

DEVELOPMENT OF AN AIR BEARING
TRANSPORTATION SYSTEM

PREPARED FOR
TRANSPORT CANADA
TRANSPORTATION DEVELOPMENT CENTRE

By
DR. J.H. STANNARD
UTDC RESEARCH AND DEVELOPMENT LTD.

DATE: 84:10:31

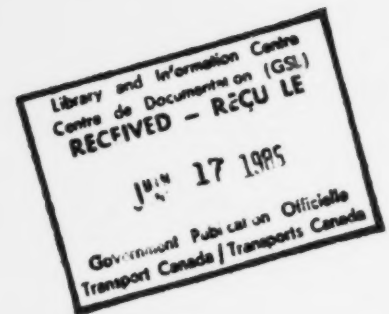
DSS CONTRACT NO. OSD 83-00047

**UTDC R&D**

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FINAL REPORT _____ TP 6169 E

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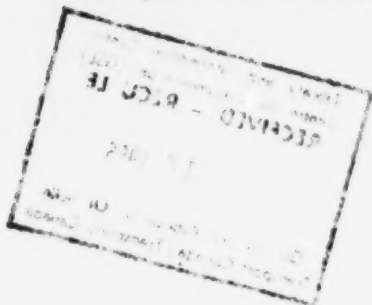


PREPARED FOR: TRANSPORT CANADA, TRANSPORTATION
DEVELOPMENT CENTRE
D.S.S CONTRACT SERIAL NO: OSD83-00047
UTDC R&D REPORT NO: 447-900-041
DATED: 84:10:31

BY: Dr. J.H. Stannard

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REPORT DOCUMENTATION FORM

1. Transport Canada Report No. TP 6169E	2. TDC Project No. 4976	3. Recipient's Catalogue No.	
4. Title and Subtitle Development of An Air Bearing Transportation System		5. Report Date 31 October, 1984	
		6. Performing Organization Report No. 447-900-041	
7. Author(s) Dr. J. H. Stannard		8. Transport Canada File No. D 1465-310-4	
9. Performing Organization Name and Address UTDC Research and Development Limited P.O. Box 160, Station "A" Kingston, Ontario K7M 6R1		10. DSS File No. 11sd.T8200-2-2600	
		11. DSS or Transport Canada Contract No. OSD83-00047	
12. Sponsoring Agency Name and Address Transportation Development Centre (TDC) 1000 Sherbrooke Street West Suite 2421 Montreal, Quebec H3A 2R3		13. Type of Report and Period Covered Final July'83 - Oct'84	
		14. Sponsoring Agency Code	
15. Supplementary Notes		16. TDC Project Officer C. A. Versailles	
17. Abstract An Air Bearing Transportation System was developed by UTDC Research and Development Limited. The technology is characterized by use of a resilient vehicle mounted shoe riding in a concave rail to provide both support and guidance. The interface is supplied with low pressure air from within the rail reducing friction to very low levels. Propulsion and braking are effected by means of guideway mounted linear induction motors (LIM's). A 40 m long development and demonstration system was built at the UTDC Kingston test site consisting of two stations, a pedestrian crosswalk, a straight and curved guideway. The propulsion system consisted of 21 LIM's sequentially energized by a variable frequency, variable voltage supply. Vehicle speed and position was computer controlled through guideway mounted sensors and equipment. The system was successfully demonstrated for 3 months and some 42,550 trips between stations carried out at an average speed of 2 m/s with a four-passenger vehicle.			
18. Key Words Transporter, Linear Induction Motor, Transit, Public Transportation, People Mover, Compliant Pneumatic Air Pallet		19. Distribution Statement Limited number of copies available from sponsoring agency on request.	
20. Security Classification (of this report) Unclassified	21. Security Classification (of this page) Unclassified	22. No. of Pages 393	23. Price

FORMULE DE DOCUMENTATION POUR RAPPORT

1. N° du rapport Transports Canada TP 6169E	2. N° de l'étude — CDT 4976	3. N° de catalogue du destinataire	
4. Titre et sous-titre Development of An Air Bearing Transportation System		5. Date du rapport 31 octobre, 1984	6. N° du rapport de l'organisme exécutant 447-900-041
		7. Auteur(s) Dr. J. H. Stannard	8. N° de dossier Transports Canada D 1465-310-4
9. Nom et adresse de l'organisme exécutant UTDC Research and Development Limited P.O. Box 160, Station "A" Kingston, Ontario K7M 6R1		10. N° de dossier — ASC 11sd.T8200-2-2600	11. N° de contrat — ASC ou Transports Canada OSD83-00047
		12. Nom et adresse de l'organisme parrain Centre de développement des transports (CDT) 1000 o., rue Sherbrooke Suite 2421 Montréal, Québec H3A 2R3	
13. Genre de rapport et période visée Final juillet'83 - oct'84		14. Code de l'organisme parrain	
15. Remarques additionnelles		16. Agent de projet — CDT C. A. Versailles	
17. Résumé Ce rapport concerne le système de transport sur coussin d'air étudié par UTDC Research and Development Limited. Ce système fait appel à un véhicule muni de patins souples, supporté et guidé par des rails concaves à la surface desquels une mince couche d'air basse pression sert à réduire substantiellement les forces de frottement. La propulsion et le freinage sont assurés par moteurs linéaires à induction implantés dans la voie. UTDC a construit dans ses installations de Kingston une ligne expérimentale longue de 40 m comportant un tronçon en courbe, ainsi que deux stations et un passage piétonnier. La propulsion est assurée par 21 moteurs linéaires à induction, alimentés séquentiellement par une source à tension et fréquence variables. La vitesse de marche et la position du véhicule sont contrôlées par ordinateur couplé à des détecteurs implantés dans la voie. Le système a subi avec succès 3 mois d'essais au cours desquels un véhicule 4 places a réalisé 42,550 trajets, à une vitesse moyenne de 2 m/s.			
18. Mots-clés Transporteur hectométrique, moteur linéaire à induction, transports publics, transports en commun, manutention sur coussin d'air.		19. Diffusion Le CDT dispose d'un nombre limité d'exemplaires.	
20. Classification de sécurité (de ce rapport) Non classé	21. Classification de sécurité (de cette page) Non classé	22. Nombre de pages 393	23. Prix

ACKNOWLEDGEMENT

The work on the development of an Air Bearing Transportation System has been carried out under a contract approved by the Department of Supply and Services on behalf of the Transportation Development Centre dated 31 July 1983.

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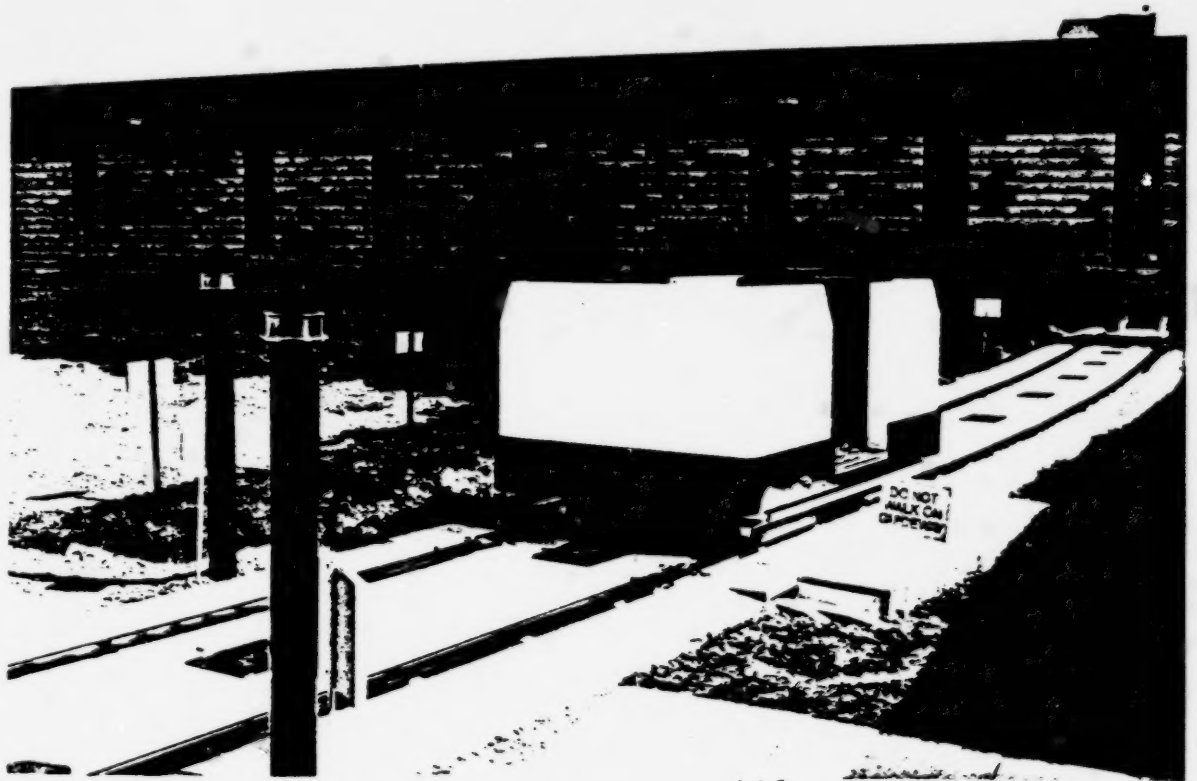
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VIEW OF TRANSPORTER DEVELOPMENT TRACK AND VEHICLE

1.0 INTRODUCTION**1.1 BACKGROUND**

The project described here is the development of an Air Bearing Transportation System, termed "Transporter". The Transporter is a lightweight automated guideway people mover system designed for the low-speed, low-capacity people mover market. The system has been based on several innovative Canadian technology concepts, developed with support by TDC through two different projects.

The first project was a study which included a market review to determine possible application opportunities for air bearing technology in the transit industry and likely operational requirements. In addition, an engineering study to determine preliminary system configurations and a general operating scenario of the system, including order of magnitude cost estimates, were undertaken.

This preliminary study concluded that the concept of marrying compliant air bearing technology with linear induction motor (LIM) in-track technology (the Transporter system) provides the potential for a high-quality, low-cost transportation system that would be very competitive with other systems developed for the low-capacity people mover market. A prototype system was built in an inside environment and demonstrated very encouraging results for further development. The study concluded that the potential reliability of the system, combined with the low capital and operating costs in comparison to competitive systems, creates the opportunity for a new product with large market potential. The report TP 4766E (1) prepared for TDC identifies the level of marketing and engineering efforts that UTDC invested in the preliminary study program.

The second TDC project described here involves the actual development of an experimental Air Bearing Transportation System.

This project included the detail design, construction and operational demonstration of an experimental Transporter system built at the UTDC Transportation Development Centre at Kingston, Ontario. The purpose of the project was to demonstrate and evaluate the technical feasibility of the design solutions that have been developed through previous engineering efforts. The project cost of approximately \$580,000 was shared equally by TDC and UTDC.

In addition to the specific projects outlined above, UTDC has also undertaken considerable work to further define and segment the low-speed, low-capacity people mover market, and to identify specific application opportunities. The Company has contracted outside consultants as well as utilized its own staff to evaluate the market. This work has provided the

Corporation with considerable insight into the market segments that will likely find automated guideway systems of interest, and the major performance requirements that must be achieved to meet the user requirements.

1.2 PROJECT OBJECTIVES

Overall Objectives

The project had the overall objective of improving the intermodal transfer of freight and passengers.

Project Objectives

The specific objective of the project (2) was to develop and demonstrate an experimental transportation system based on the use of compliant air bearing suspension technology and linear induction motor (LIM) propulsion technology.

1.3 PROJECT METHODOLOGY

The project was carried out in four milestone segments:

- o Milestone #1 - This milestone consisted of the conceptual design carried out by UTDC R&D of a demonstration track for the Transporter system. Included in this phase of the work was the evaluation of some technical features of the system which were not detail designed and implemented within the current program.
- o Milestone #2 - This milestone encompassed the detail design work on the development of a demonstration air bearing Transporter system.
- o Milestone #3 - The work included the construction and commissioning of the demonstration track. The commissioning test plan was developed and preliminary integrated system tests, insulation tests and friction tests were carried out with recommendations on potential design improvements:
- o Milestone #4 - The work carried out was the demonstration phase of the Transporter link. A series of selected 35 mm slides and a VCR video cassette of the operating system were prepared for TDC.

1.4 ORGANIZATION OF THE REPORT

In this final report, the objectives, the design approach taken, and results of the project are summarized. The report is organized along the lines of the milestone segments described above, with overall conclusions and recommendations resulting from the work. Included as attachments to the report are the most relevant of the detailed working documents of certain aspects of the work, generated as the program was carried out.

2.0 SYSTEM DESIGN

2.1 OPERATIONAL REQUIREMENT

In order to discipline the development and demonstration process, an operational requirement for a low-speed, low-capacity people mover was developed. This operational requirement was based on both UTDC market assessment and the stated TDC objectives, and is summarized below:

- o Small vehicle suitable for 4 passengers and luggage or 350 kg freight payload.
- o Straight track operation.
- o Curved track operation.
- o Outdoor, unprotected environment.
- o Loading and unloading areas.
- o Real passenger load (as opposed to technicians or test engineers).
- o Pedestrian crossing.
- o Low-speed operation (2½ to 5 km/h).
- o Automatic operation.

2.2 GUIDEWAY

The most difficult criterion to satisfy was that of providing a real, untrained passenger load. After consideration of building locations and traffic flow on the UTDC site, the guideway location shown in Figure 1 was selected. The track centreline is 40 m long and both straight and curved track is included, with stations at each end. The track crosses a pedestrian walkway close to its midpoint and is uncovered throughout its length.

With the current Transporter system technology a constraint on layout is the amount of tolerable track curvature. The shoe that supports the vehicle is constructed of an elliptical outer cover of relatively thick (2.25 mm) plastic, with a filler of resilient wound cellulose. This shoe is extremely stiff in a lateral sense, and thus does not deform laterally to accommodate curvature in the track. This results, in the extreme, in sliding contact

between the shoe and rail, and an increase in friction in curves. This can be alleviated by reducing shoe length at the expense of increased friction in straight line operation. The result is an optimum shoe length for any given track layout. Based on this estimate of curving performance it was necessary to restrict track lateral radius of curvature to the range 60 to 80 m with the objective of maintaining the friction coefficient in the curves below an approximate value of 0.055. This value of friction represented a realistic limit for the propulsion system in terms of thrust.

The analysis of curving capabilities was carried out during the Milestone #1 segment of the work and is detailed in Attachment A1.

The resulting layout, after consideration of all constraints, is 40 m long. This centreline length consists of a symmetrical arrangement of a 3 m emergency overrun section, 2 m vehicle parking length, and 3 m of acceleration or braking zone and 24 metres of cruising zone. The two curves have a radius of 72 m resulting in a total of 22 linear metres of curved track and 18 linear metres of straight track. The guideway is level throughout.

The guideway has the function of supporting and protecting the rails (and hence the vehicle), linear motors, sensors, power and air distribution, and any experimental test equipment. The outdoor location adds the requirements that water be drained and snow easily removed from the guideway. The nature of the site and crosswalk demanded an unobtrusive, low-profile system approximately at grade elevation. The harsh outdoor environment, particularly for winter operation, made reinforced concrete the best choice for guideway material. The rails, sensors, and linear motors are all mounted flush with the upper surface, enabling easy snow removal. Three longitudinal trenches are provided; the two outer ones at 1000 mm gauge are for the rails, the inner trench for LIMs, sensors and power distribution. The concept is shown in Figure 2. The central trench between LIMs is covered with concrete paving slabs.

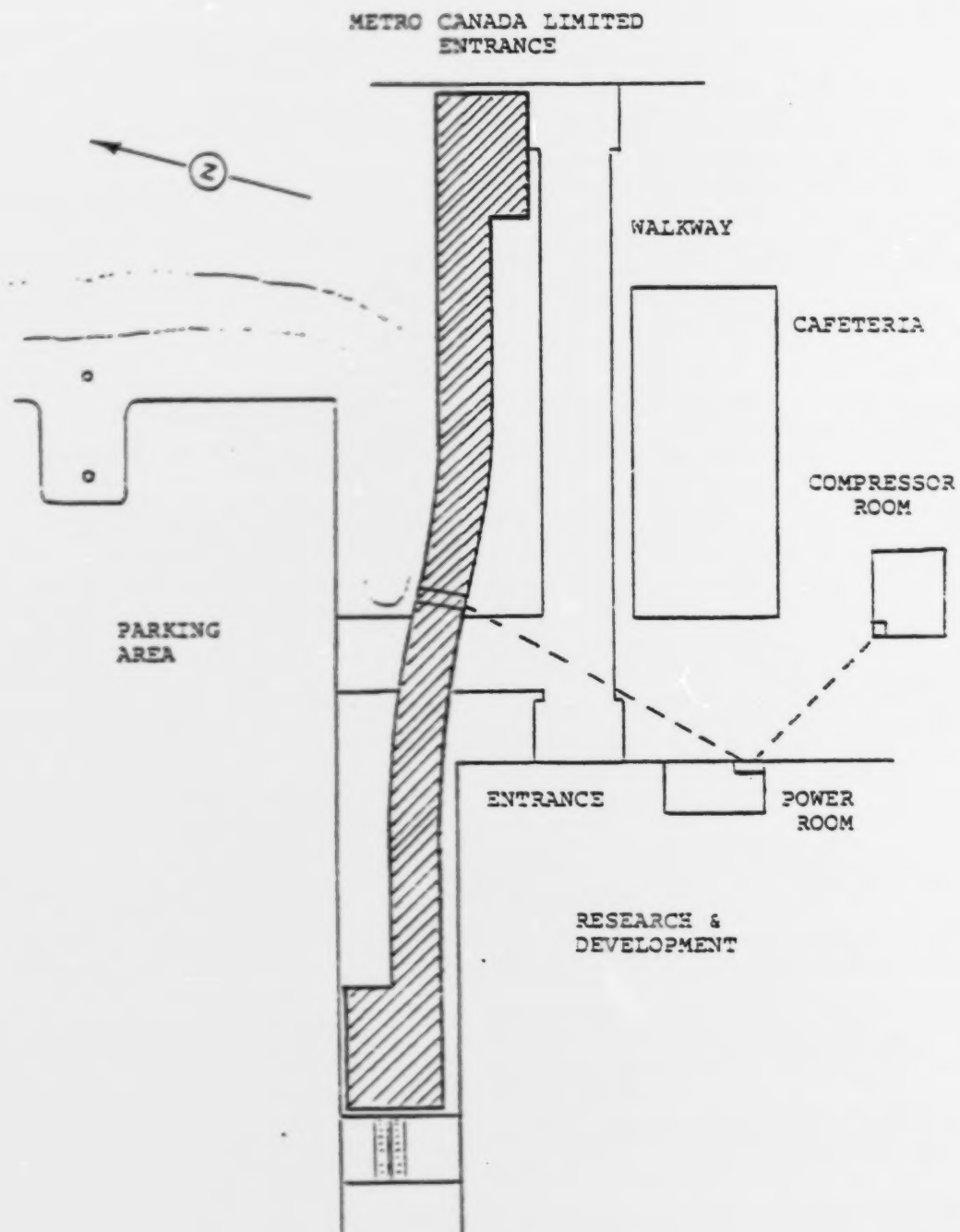


FIGURE 1: TRANSPORTER DEMONSTRATION TRACK LAYOUT

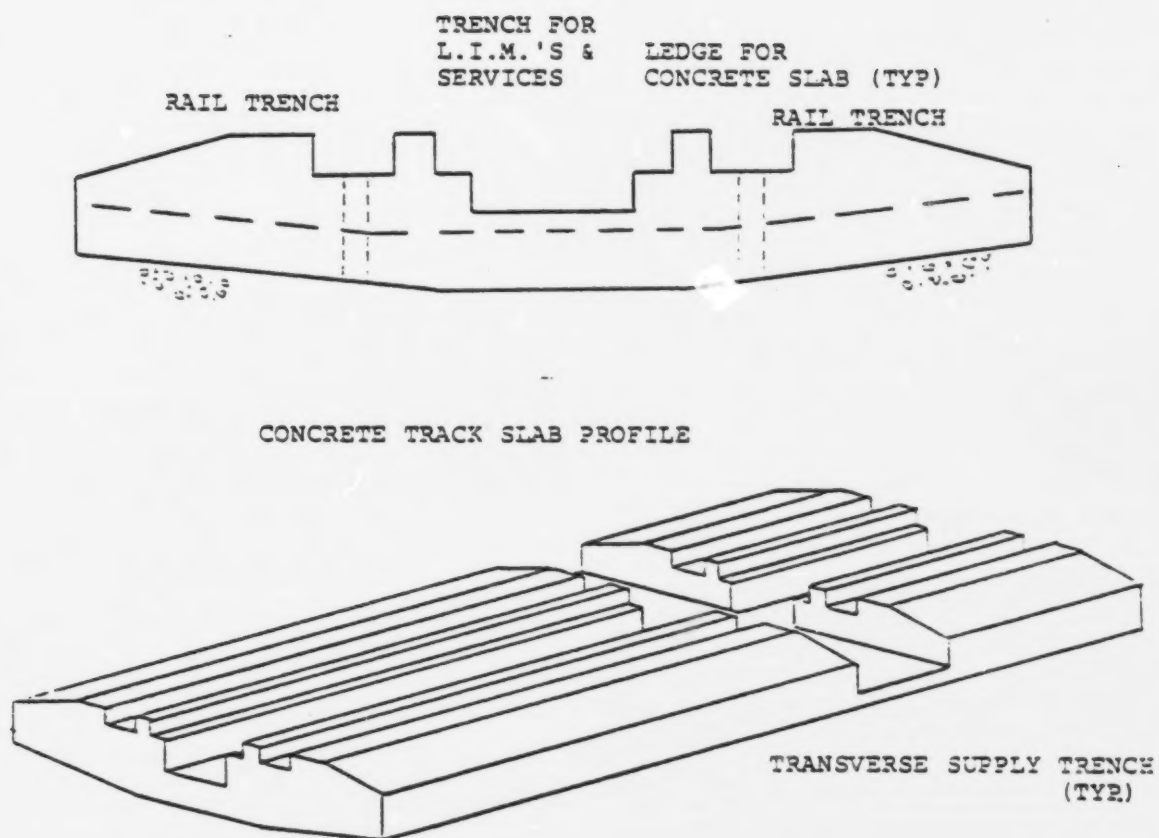


FIGURE 2: TRACK SLAB LAYOUT

2.3

VEHICLE

Operation on curved track is made possible by articulated shoes. At each side of the vehicle there are two shoes, each mounted on a swivel which allows limited rotation in pitch and yaw, but which is stiff in roll. The basic structure consists of a simple welded aluminum grid, fabricated from square extruded tubing. (See Figure 3.) Overall dimensions with a simple plywood body attached are: length 2.4 m, width 1.2 m, and height above rail 1.2 m.

The reaction rail necessary for propulsion is mounted, full length, below the centre of the vehicle. For test purposes the reaction rail can be adjusted in height. The engineering test vehicle without body weighs 117 kg. Essentially any body style or freight-carrying floor could be mounted on this chassis.

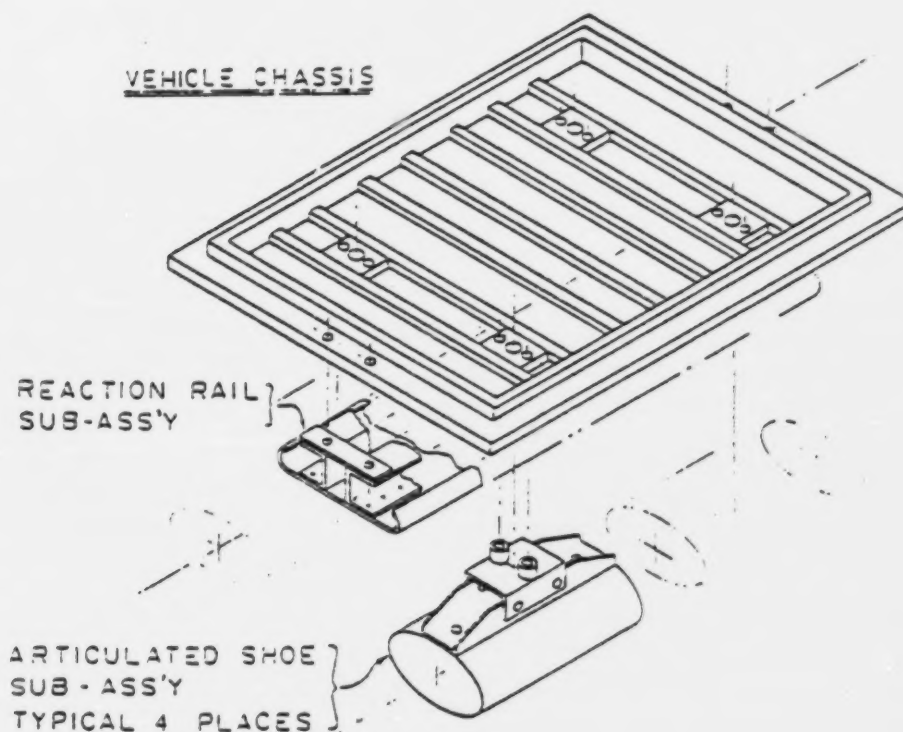


FIGURE 3: ENGINEERING TEST VEHICLE

2.4 PROPULSION AND CONTROLS

2.4.1 Propulsion

The propulsion system consists of a series of discrete linear motors embedded in the guideway on the centreline. Each motor is approximately 0.4 m long, 0.3 m wide and 0.1 m deep. The motors are of 3-phase design, connected in star configuration, and develop between 340 and 900 N of stall thrust depending on the winding chosen. The synchronous speed is 6.5 m/sec, thus necessitating some form of speed control, as discussed in the following section. From Reference 1 the friction level for 0.9 m shoes will vary from 0.027 on straight track to 0.047 in the curves assuming a well polished dry rail and conditioned shoe at a track air pressure of approximately 200 KPa. For conceptual design purposes it is prudent to allow for 50% greater friction levels when calculating required LIM thrust. It is also necessary to take into account variations in LIM thrust with effective air gap. For example, the empty vehicle might have an air gap of 11 mm, and a loaded one of 6 mm, resulting in a thrust increase from 210 N to 630 N for a nominal 900 N LIM. This offers near perfect load-weight control since thrust has increased by a ratio of 3 for a mass increase ratio of 3.33.

On the conservative basis reviewed above, the required cruise thrust for fully loaded vehicle is 345 N; thus one LIM per reaction rail length offers adequate thrust. The spacing at exactly one reaction rail length will reduce jerk to low values by virtue of the thrust increase entering a new LIM being offset by reducing thrust from the LIM being left behind.

2.4.2 Control Concepts

The major challenge to be met by the demonstration system was the development of a safe, reliable control system which would meet the simple requirements stated in Section 2.1 and possess the following additional features:

- o Push-button call from either station.
- o Safe start-up and shut-down systems.
- o Emergency stop.
- o Overheat and overload protection.
- o Detection of power, sensor, and air system failure.
- o Completely automatic, unattended operation.

Essentially four different control concepts were developed and evaluated. They are compared in Table 1. The system selected was Concept 2. In this concept the LIMs are each provided with one

CONCEPT	POSITION CONTROL	SPEED CONTROL	ACCELERATION & JERK CONTROL	MAJOR DISADVANTAGE	MAJOR ADVANTAGE	ABILITY TO MEET REQUIREMENTS
1 Passive Control	+ 0.5 m at best	+0.5 m/sec at best by varying gap height	Crude and probably unacceptable	Virtually certain to over-or-under run stopping position	Very low cost	Unlikely
2 Centrally located power distribution Variable frequency with PLC Supervisory Control	+ 0.05 m with closed loop position in terminals	+0.1 m/sec for variable payload under same weather conditions	Can be developed to meet requirements	The extent of power and control wiring	Speed of implementation and reasonable cost	Yes
3 Distributed Intelligence and Voltage Thrust Control	+ 0.05 m	Better than +0.1 m/sec All Conditions	Will be easy to meet requirements	Development time and cost	Could be basis of production system	Yes
4 Central Intelligence and Voltage Thrust Control with Multiplex Signalling	+ 0.01 m might be achieved	Better than + 0.1 m/sec All Conditions	Will be easy to meet requirements	Development time and cost	Could be basis of production system; very flexible	Yes

TABLE 1: COMPARISON OF CONTROL CONCEPTS

sensor, and are all supplied with 3-phase power from a central distribution point. Each LIM is wired individually to a contactor which is signalled to close and open by a programmable logic controller, using the sensors as inputs of vehicle position. Speed would be controlled simply by using a variable frequency supply such that the required thrust would intersect the decreasing available thrust at a reduced operating frequency.

The overall Control System Block Diagram is shown in Figure 4, and more detail is provided on the control system philosophy and design in Attachments A4 and A5.

In order to provide a better resolution of vehicle position, up to 10 pulses per vehicle from one sensor could be provided simply by a notched metallic bar such that the proximity sensor would react only to the metal between notches. Since the speed control is passive, i.e. limited to a band by use of the thrust-speed characteristics, precise stopping will require either extensive field trials to adjust the system under all conditions, or a simple closed-loop position control in the terminal areas.

2.5 AIR SUPPLY SYSTEM

The general requirement of reliable, low-maintenance operation and minimum external vibration eliminated reciprocating compressors as an air source. Reciprocating compressors, unless of "oil-free" design, cause problems of oil contamination of the air when worn. A rotary screw or centrifugal compressor would provide the required low vibration and long life, but centrifugal compressors are rarely designed for such low flow-rates. When we take into account all the requirements, a rotary screw type compressor fitted with filters and a dessiccant type dryer proved to be most suitable, and is readily available from a wide range of manufacturers.

Noise from the compressor will be mostly air-borne and in a frequency range of 150 to 1000 Hz. In order to reduce compressor noise to the existing background level of less than 69 dB an acoustic enclosure was installed. The air was filtered to the 5 micron level and dried to a dewpoint of -40°C . The acoustic design is described in Attachment A6

2.6 ENVIRONMENTAL CONSIDERATIONS

2.6.1 Requirements

All-weather operation was defined to be operation with a minimum of service interruption over the range of summer and winter temperature and relative humidity conditions and precipitation. These conditions for the Kingston Test Site are summarized below:

- o Temperature Dry Bulb - Summer High $+33^{\circ}\text{C}$
 - Winter Low -24°C

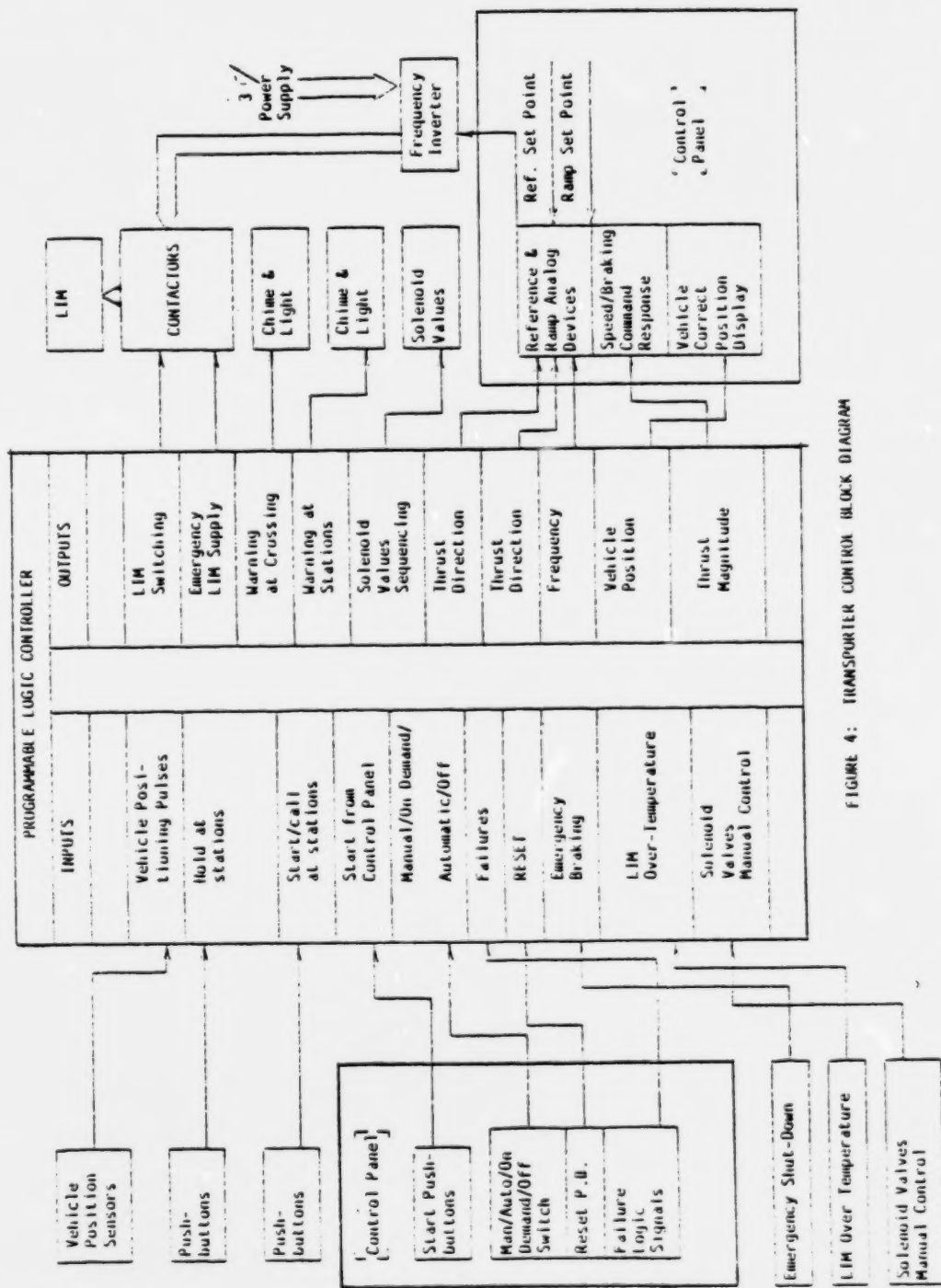


FIGURE 4: CONTROL SYSTEM BLOCK DIAGRAM

FIGURE 4: TRANSPORTER CONTROL BLOCK DIAGRAM

- o Wet Bulb - Summer High +19°C
- o Precipitation
 - Rain 0.96 m/year total
 - Snow 0.2 m average winter depth

The temperature range necessitated provision for track expansion, the humidity required a track air supply dryer system, and the precipitation required water drainage and some form of snow removal. Each is discussed below and, in addition, the effects of wind and track contamination are considered.

2.6.2 Track Heating System

Rain, either as discrete droplets or collected in the rail trough, does not interfere with the air bearing action once air has been supplied to eject water from the centre passage of the rail. This can take up to a minute because of the reduced flow of water relative to air through the small air holes in the track surface. Thus, a wet or filled track can be cleared of water without any special provision other than a few minutes of air flow on each section before operation.

Large accumulations of snow or ice can be removed mechanically (e.g., shovel or snow blower), leaving a thin layer of compacted snow or ice on sensors and LIMs and in the concave rail surface. Similarly, freezing rain conditions would also produce a thin layer of up to 6 mm on these surfaces. Operation of virtually all proximity type sensors and LIMs is unaffected by such accumulations as long as mechanical interface is avoided. Ice and snow removal from the rail surface and, in the case of ice, potentially from the rail centre passage, is also easily dealt with by providing a continuous supply of low pressure air. Alternative means for achieving this are chemical de-icing, infra-red heat, plate-type resistance heaters, heat trace cable, parallel element electrical heaters and heating of the air supply.

The demonstration track was constructed using the air heating system because of availability and low cost, and is described in Attachment A3.

2.6.3 Expansion Joint

The rail currently installed is fabricated from hollow aluminum extrusion. The extremes of temperature to which it will be subjected cause expansion and contraction of each rail section (7.62 m long) at a rate of 25×10^{-6} m/m°C. For a realistic temperature range of -20°C to +40°C, this necessitates allowance for a total movement at each joint of 11.4 mm. Thus, typically the system would be assembled at +10°C, with a 6 mm gap at each rail joint, leaving a gap of 0.3 mm at +40°C and 11.7 mm at -20°C. The joint must allow for the movement, and in addition air must be carried across it without leakage at all temperatures. The joint design selected is described in Attachment A2.

2.6.4 Shoe Design and Rail Contamination

Outdoor and all-weather operation implies a certain degree of debris tolerance for the system. The only critical area, with the exception of large objects, is the shoe-rail interface. Debris can be loosely classified into adhesive and non-adhesive substances. At this point, no testing of the tolerance to adhesive substances has been carried out. Dry substances of small particle size are blown off the rail by the air, and large particles are brushed aside by the shoe. A shoe-mounted scraper blade and track brush for each shoe can be installed to clean the track. This will eliminate any particles which might potentially be trapped between the shoe and the rail.

2.7 OPERATIONAL STUDIES

In the operational studies a number of potential developments were assessed for feasibility, namely switching, directional shuttle, queue and restart, horizontal separation control and obstacle detection.

It was concluded that a simple switch capable of being traversed by a vehicle with articulated shoes could be developed by elastically deflecting short sections of rail from the straight ahead position to match a curved stationary rail. Vehicle testing showed that the gaps and tolerances expected could be negotiated by a vehicle.

The required technology for a directional shuttle is a reliable, low-cost, switch and accurate position and speed control for all vehicles. The switch was discussed in the previous paragraph. The multiple vehicle problem also necessitates "unambiguous" position sensing, and given this sensing of sufficiently fine resolution, a speed and position control system becomes relatively easy to implement.

Unambiguous position to a high resolution can be obtained by a notched sensor activation bar. Note that the sensor density may be increased in station and storage areas where vehicle spacing may become very small, of the order of less than 1 m. Once a high resolution output for speed and position is obtained from the sensors, then vehicle speed and position control can be treated as any classical control problem, even though the actual motor doing the controlling is changing all the time.

The problem of providing a viable obstacle detection system can be broken down into a series of components, namely the nature and size of the obstacle, the means of detection, and the action taken on detecting an obstacle. In the case of Transporter it would be desirable to detect objects large enough to impede or damage the vehicle, and particularly people on the track at stations and crosswalks. Systems that might be considered include Doppler radar, ultrasonic detectors, infrared detectors, load cells, electrostatic detectors and TV cameras with a motion detector device. At the present time it is known that this last option is relatively undeveloped, at least in the civilian sector, and unlikely to be developed in a time scale that would make it useful for our purpose. Detection of a person on a crosswalk could easily be achieved via a load cell or load sensitive mat which would slow or stop the vehicle and activate alarms.

Based on the review carried out it was concluded that the simultaneous requirements of both sensitivity to obstacles and avoidance of spurious alarms was capable of resolution, but that a substantial and long-term research and development effort was required. It was concluded, however, that it is possible to design and operate an automatic system without obstacle detection, provided a secure right-of-way is used.

3.0 INSTALLATION AND COMMISSIONING

3.1 REVIEW OF INSTALLATION PROCESS

The civil works included all excavation, backfilling, form work, concrete pouring, finishing and erection of compressor hut on a concrete pad. Winter construction in extremely cold (-25°C) weather and deep frost penetration made progress slow and increased costs. This necessitated longer contractor time on site and the use of a large heated tent for protection of the newly poured concrete.

Problem areas that have shown up later in the program are the poor concrete properties near the surface, evidence of some freezing during the cure period, the uneven surface of the rail slot, necessitating time-consuming repairs and shimming, and insufficient clearances around the LIM and sensors, unnecessarily increasing installation time. (See Attachment A7 for details)

Rail installation to an approximately 70 m curve proved relatively easy. The problems were concentrated at the joints, especially track joints at which some thermal expansion had to be allowed. This usually was a result of poor welding on the rail clips and rail plugs. Clearly, good quality control procedures must be implemented in a production installation.

The objective of providing a clean, dry, heated, and quiet air supply was met in all respects by the design described in Section 2.5. Noise measurements proved to be satisfactory. Initial compressor operation was achieved during freezing weather, and no problems of system icing occurred. A test of the heater system showed that it did function, but its overall efficiency and reliability must be determined in the forthcoming winter.

Installation and testing of the electrical system proceeded largely without a hitch and a local electrical contractor carried out the work efficiently and on budget. The sole exception was the problem discovered of failed LIM insulation, reported in Reference 5 (Attachment A7). In brief, the insulation resistance of the LIMs fell to unacceptably low levels, especially after rain. Eight (8) of twenty-one (21) LIMs were rewound and are currently acceptable.

Two features of the control system proved to consume much time and effort during installation and commissioning:

- o The proximity sensors selected have limited sensing range and need adjustment very close to the vehicle. This occasionally results in mechanical interference between sensor and vehicle.
- o The user memory of the Texas Instruments PLC chosen was limited, resulting in very time-consuming program

manipulation to achieve simple software changes. This problem was not inherent in the PLC, merely in the particular model chosen.

3.2

REVIEW OF COMMISSIONING RESULTS

The commissioning Test Plan is described in detail in Attachment A7 Reference 5. In general, the individual system tests were routine and such tests as wiring continuity and wiring coding are not reported unless a specific anomaly with relevance to Transporter design and construction was noted.

During integrated testing, speeds up to 3.0 m/s were achieved at low vehicle weights and the design speed of 1.0 m/s achieved at all required test weights. The vehicle acceleration and braking system, including emergency stop, met all requirements. The major problem areas were:

- o Eliminating mechanical interference between vehicle and track at all weights.
- o Obtaining consistent stopping positions that would allow automatic system restart.

The small air gaps required are discussed in Ref. (1) and are a direct result of LIM design for 60 Hz. An increase in allowable air gap would greatly simplify vehicle and track design.

After considerable testing it was concluded that routine automatic vehicle operation at 2 m/sec was possible. All demonstration operation was carried out at this speed.

4.0 DEMONSTRATION

4.1 DEMONSTRATION OBJECTIVES

The plan of operation for the demonstration program was to commence running at the regular starting time for each day and to break into the operation only when specifically required for the purpose of providing demonstration rides or to gather test data, e.g., from friction tests. Accumulated experience indicated that riders could board the vehicle in either station at any time, except during special tests, and all UTDC personnel and visitors were encouraged to do so.

Apart from a number of failures of some of the commercially supplied equipment which reduced the daily running time, this plan was adhered to throughout the demonstration phase and, as experience was accumulated and service failures were reduced, the number of trips increased dramatically. A chart of the weekly operations is shown in Figure 5.

The demonstration program results are described in detail in Reference 6, included in this report as Attachment A8.

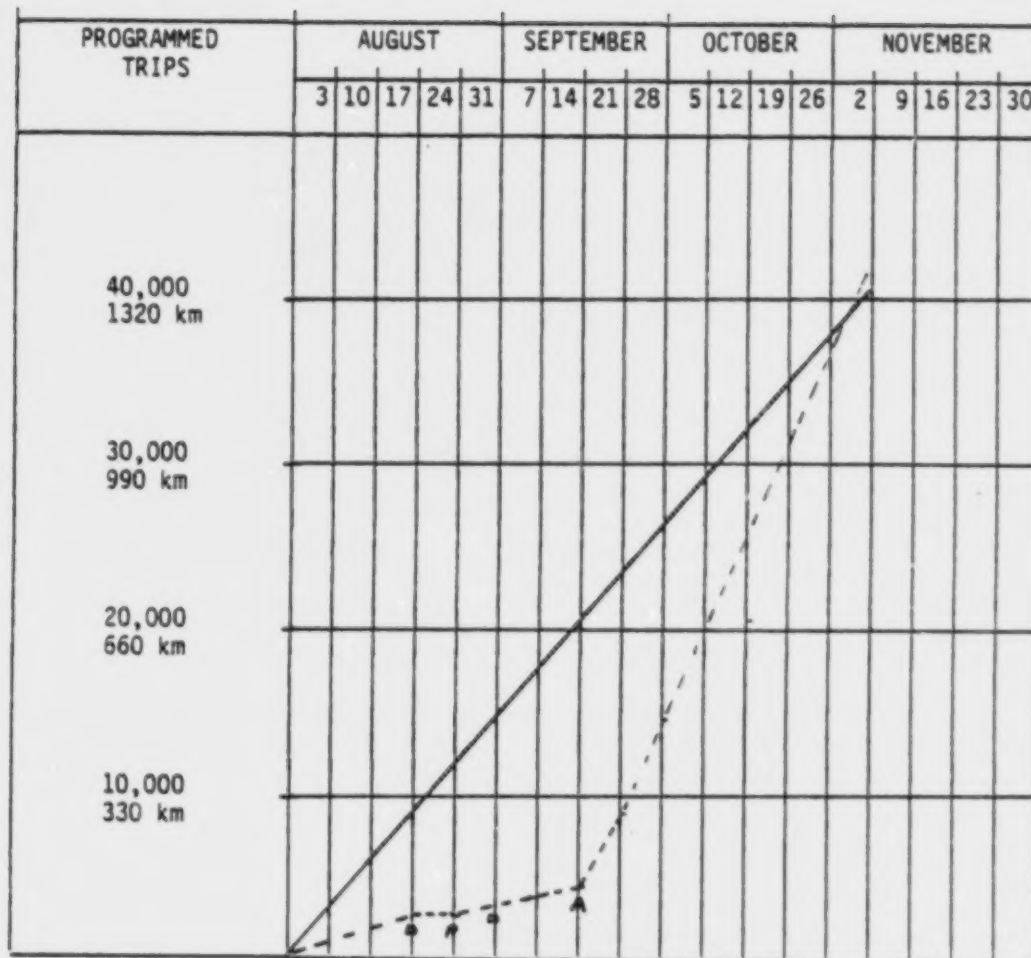
4.2 PERFORMANCE EVALUATION

The continuous operation plan provided a method of assessing the performance of the system. A number of anomalies occurred and several defects in commercially supplied items required special attention.

4.2.1 Track and Track Bed

Generally, the track and track bed performed as expected. The tendency for the concrete road bed to produce a fine powdery dust caused the shoes of the vehicle to pick up the dust, especially during high-humidity conditions, and the results were reflected in the apparent wear of the coloured, soft, anodized surface of the rail. The wear was not measurable with the test equipment available, i.e., less than 0.025 mm, but, in some areas, the coloured layer was completely removed from the rail. This did not appear to affect the running of the vehicle during daily operation in dry weather, but the bare aluminum areas did tend to oxidize overnight, when the system was shut down, and the drag rise following this was quite noticeable until considerable running repolished the rails.

The washing action of heavy rain appeared to increase the production of the powdery cement. Subsequent treatment of the concrete with a curing and sealing agent reduced the surface powdering. With this treatment, with longer operational periods, the rails began to take on a noticeable "polished finish", and drag or friction was reduced dramatically.



TARGET: 8 hrs/day operation for 63 working days

D - Drive Failure

A - Automatic Operation

P - Power Failure

———— Planned

----- Actual

FIGURE 5: TRANSPORTER DEMONSTRATION TESTING

4.2.2 Shoes and Shoe Carriers

The shoes suffered considerable longitudinal scratching following continuous operation when fine and coarse gravel was deposited on the track. These scratches tended to "pick up" the cement dust from the road bed, and the subsequent cement "paste" caused the brown anodized surface to wear away. The wear was not noticeable on the shoes but increased drag or friction was noted while the open aluminum surface of the rail was in the oxidized state. Subsequent "polishing" of the area reduced the drag significantly. When the "scratched" shoes were removed at 3370 trips for evaluation, a replacement set was installed, and 30,000 trips were accomplished before they were removed. The second set of shoes was fitted with a set of track cleaning brushes which considerably reduced shoe contamination, shoe wear, and rail wear.

4.2.3 Linear Induction Motors

During commissioning 8 of 21 motors were found to have unacceptable insulation. These motors were rewound or reinsulated as required and proved to be acceptable in service. The linear induction motors were originally installed with the windings dipped and sealed with epoxy for weather protection and a fibre plastic cover epoxied to the face of the laminations for surface protection. These operated satisfactorily, but the covers suffered damage from pedestrian traffic. Subsequently, a total encapsulation of a LIM in epoxy resin was carried out. This LIM was installed in the area of greatest pedestrian traffic and has proven successful over the full operating range of duty cycle and has sustained no damage.

4.2.4 Reaction Rail

A reaction rail having a greater thickness of the aluminum cap and a reduced thickness of the back-iron was installed prior to the demonstration phase and has demonstrated improved performance, as well as being lighter in weight. This reaction rail was developed using data from the 60 Hz LIM program and resulted in reduced downforce.

Some minor adjustment of the rail-to-LIM gap was initiated to allow for shoe compression and to reduce the possibility of striking the LIM while the vehicle is overloaded. There is reserve power available to accomplish this, and the system tends to run much more smoothly (less jerk) with the greater gap, although load-weight compensation is not as good.

4.2.5 Sensing Rail and Proximity Sensors

These items have been the cause of some concern during the demonstration phase. The limited range of the proximity sensors (13 mm) requires the sensing-rail-to-proximity-switch clearance to be maintained within extremely close tolerances or signals to the computer will be lost. Proximity switches with much greater operating range will be required for operational systems. The switches can then be installed "below grade"; this will ensure protection from pedestrian traffic and other interferences and still permit an adequate signal to the computer. It proved time-consuming to adjust the sensors used to the ± 1 mm tolerance required.

4.2.6 Control System Operation

The control system operated with the required reliability and ease of use with the exception of one feature, that is, the precise control of stopping position within the station. The major feature preventing complete solution of this problem was the limited memory size (1K) of the Texas Instrument's Programmable Logic Controller, which was selected to control all the system functions including failure monitoring, vehicle position control, vehicle speed control and station operations.

The result of the limited memory size was that the stopping control was of an open-loop rather than closed-loop nature with a limited ability to compensate for changes in track friction, vehicle mass, shoe condition and head or tail winds.

An attempt was made to correct the amount of braking applied by measuring the initial rate of deceleration and using a simple algorithm to vary the length of time over which reverse thrust was applied, and the time at which it was initiated. The total scatter in stopping position, if a simple fixed braking rate was used, would be ± 0.2 m from a speed of 2 m/sec. The simple algorithm which resulted in "adaptable" open-loop gave a considerable improvement with a scatter in the range ± 0.1 m. Occasional under- or overshoot of a further ± 0.1 m was experienced (approximately 1 per 100 trips), which necessitated manual repositioning of the vehicle and system restart. It should be noted that the overshoot into the emergency zone was much less frequent (approximately 1 or 2 occurrences a week) and was never more than .6 m from the end of the desired stopping distance in normal operation.

In contrast, speed control in the cruise region proved to be better than anticipated with a range of some 16 steps in frequency between 15 and 50 Hz being sufficient to control vehicle speed under all conditions to 2 m/sec with an error in the cruise region of less than 5%. Repeatability on total trip time was also much better than $\pm 5\%$.

4.2.7 Motor Drive Control - Frequency Inverter

The variable frequency inverter drive in general proved to be a flexible and controllable device for energizing the LIMs and for most of the demonstration operated in a most satisfactory manner at all vehicle speeds and weights. There were isolated incidents, the most serious of which resulted in shut down of the system while repairs were effected. This massive failure of the motor drive control was traced to a logic error allowing too many LIMs to be activated simultaneously. This severely impacted the operational demonstration running during the month of August. The inclusion of a "super fuse" to protect the frequency inverter rectified the problem, and further detail work subsequently prevented unplanned random activation of the sensitive "super fuse". The device consists of an extremely fast microprocessor-controlled solid state circuit breaker in the DC link between rectifier and inverter in the motor drive unit. It senses overcurrent and shuts the system down in a safe manner. The motor drive control operated satisfactorily once the solution was identified and changes implemented.

4.2.8 Friction Tests

A series of friction tests at varying loaded weights was carried out. Friction levels were reduced during operation of the track, as both rails and shoes became polished, to a value of .025 on straight track and .022 in the 70 m curves. These values are in fact below the expected levels determined in the conceptual design task.

The track joint misalignment and rough finish at the ends of the rail contributed to increased friction and shoe wear in these regions. Careful attention to the track joint alignment and gap is of great importance. Typically friction at the joints is double the normal values.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 DEMONSTRATION OPERATIONAL ACHIEVEMENT

The air bearing transportation demonstration system has been installed, developed and demonstrated. During the course of the demonstration, 42,550 trips of 33 metres were completed successfully. The system continues to operate reliably, with the exception of the stopping algorithm, which periodically allows the vehicle to overshoot its required stop position. This problem is directly related to the limited memory capacity of the programmable logic controller (PLC) rather than any inherent difficulties with the Transporter system.

5.2 CONCLUSIONS

- o The control system proved the software design concept and the system operated with satisfactory reliability, allowing for the limited memory capacity of the programmable logic controller. The limited memory capacity of the PLC made it necessary to erase other parts of the program from the memory in order to functionally prove new program segments. This limitation would be eliminated in a real system application by replacing the current PLC with one of sufficient memory capacity.
- o After an initial "breaking-in" phase, system performance stabilized and daily operation at a very high availability was achieved with minimal maintenance. The availability achieved during the demonstration would meet project real system requirements.
- o Successful operation of the demonstration system was possible in all conditions of high summer temperature (to +35°C), rain, light snow and moderately freezing temperatures. Testing in heavy snow, blizzard conditions and extreme low temperatures (to -30°C), in order to determine system operational limitations remains to be examined, as well as to define areas of the system requiring further development.
- o Vehicle performance was smooth and jerk-free and meets current and projected design requirements.
- o System vibration and noise is very low. The major noise contribution was the "sounding board" effect of the light plywood and balsa body of the vehicle, which would be eliminated in a real application design by soft mountings. There was some noise generated by a loaded vehicle while it passed over a LIM. However, no attempt has been made to dampen this "hum" and further development in this area is required.

- o The air supply system has been successfully developed, and subject to a definitive heater test, could be utilized in any future system design.
- o Curving capability to the limit of a radius of 72 metres was achieved. This was approximately the elastic limit of achievable horizontal bend of a rail by normal displacement using stop blocks and leverage. Further bending or displacement would require mechanical or hydraulic means of "rolling" or extruding the rail. Using the appropriate shoe length for the curving radius and articulating the suspension proved satisfactory for the fully loaded vehicle requirement and the coefficient of friction on the curving section proved to be slightly lower than the original calculated figure.
- o The rail joint design, although serviceable, requires improvement in gap control, especially in the curved sections of rail.
- o A LIM design suited to Transporter with a larger air gap is required to simplify the vehicle and track development problems and proximity sensors with a greater sensing range would permit fully buried and protected units.
- o A simpler track bed allowing greater clearances around the installed hardware is required in order to simplify installation and maintenance.
- o Cold weather construction should be avoided in order to reduce costs and installation problems.

5.3

RECOMMENDATIONS

It is recommended that work now be undertaken to develop purpose-designed rather than adapted hardware in order to overcome the limitations identified during this research and test system program. This would have the additional benefit of reducing the hardware and installation costs while improving overall system performance and further preparing this innovative combination of technologies for revenue service applications. In achieving these objectives the work would involve and result in new Canadian innovations in linear motor and control design and in guideway design.

6.0

REFERENCES

- 1) "Application of SailRail Technology to the Transit Industry", TP4766E prepared for Transport Canada by UTDC R&D, June 1983.
- 2) DSS Contract File Number 11SD.T82000-02-2600, Attachment "A", Statement of Work, July 1983.
- 3) "Development of an Air Bearing Transportation System - Milestone No. 1 Report", UTDC R&D Reports Nos. 447-900-009 and 447-700-001.
- 4) "Development of an Air Bearing Transportation System - Milestone No. 2 Report" UTDC R&D Report No. 447-900-022 plus attached Volume 1 (Detail Technical Notes) and Volume 2 (Drawings).
- 5) "Development of an Air Bearing Transportation System - Milestone No. 3 Report", UTDC R&D Report No. 447-900-032 plus attached detail reports.
- 6) "Development of an Air Bearing Transportation System - Milestone No. 4 Report", UTDC R&D Report No. 447-900-040 plus attached detail reports.

ATTACHMENTS

EXPLANATORY NOTE:

The attached documents are technical notes and other working documentation generated during the design and development process.

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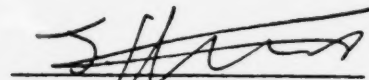
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ANALYSIS OF CURVING CAPABILITY

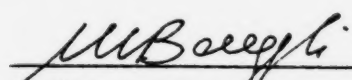
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Date: 84.03.09

PREPARED BY:


Project Engineer

APPROVED BY:


Project Manager



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SUMMARY

The ability of Transporter vehicles to accommodate lateral curves is analysed based on theoretical and empirical grounds. A shoe articulation concept is developed to improve performance.



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1.0

PURPOSE

The purpose of this Technical Note is to:

- o Determine extent to which rails can be curved without friction surface deformation (horizontal).
- o Examine known data on air gap and out-of-alignment friction.
- o Predict curvature ability for standard shoe design.
- o Conduct simple misalignment and side force tests on prototype.
- o Develop improved concept.
- o Test curving performance
- o Analyses results



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2.0 TEXT

2.1 RAIL DEFORMATION

$$\text{Stress} = \frac{E \times Z}{R}$$

where E = Youngs Modulus = 10^7 psi for Aluminum

Z = Distance to outer fibre from Neutral axis

= 2.625 in

R = Radius of Curvature, in

Allowable stress for elastic deformation = 20,000 psi

$$R \text{ min} = \frac{10^7 \times 2.625}{20,000} = 1312.5" (33.34 \text{ m})$$

Therefore any further deformation will result in permanent set. (Allowable stress of 25,000 psi results in R min of 26.67 m).

The strain of the outer fibres will be 0.002 in/in at 20,000 psi. Permanent deformation to radii as small as 20 m would seem possible without excessive deformation of the running surface (of order a few thou) provided that:

- o The process itself does not locally deform the rail
- o Buckling of the top curved face does not occur.



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2.2 AIR-GAP AND FRICTION DATA

2.2.1 Lateral Misalignment

Based on Ref. 1 the load is supported by an air pocket, typically at a pressure of 400 mm hg (53.3 kPa) above atmosphere, occupying a region some 7 cm wide, symmetrically disposed about centreline. The pressure drops to atmospheric in a region typically 1 cm wide, called the seal region. At each end of the shoe a similar region exists.

Deliberate misalignment tests resulted in a reduced average pressure under the shoe, and a distorted profile as shown in Figure 1. Since the undisturbed profile results in a friction level of 0.015 for a long shoe (> 2 m), we can relate friction linearly to the level of air support by integrating the area under the pressure curve. These results are plotted in Figure 2. Note that this relation of friction to misalignment (4 mm) applies strictly speaking to lateral movements, not curvature misalignment.

The air-gap under the centre of the shoe is of order 10 thou (0.25 mm) and in the seal region less than 1 thou (0.025 mm).

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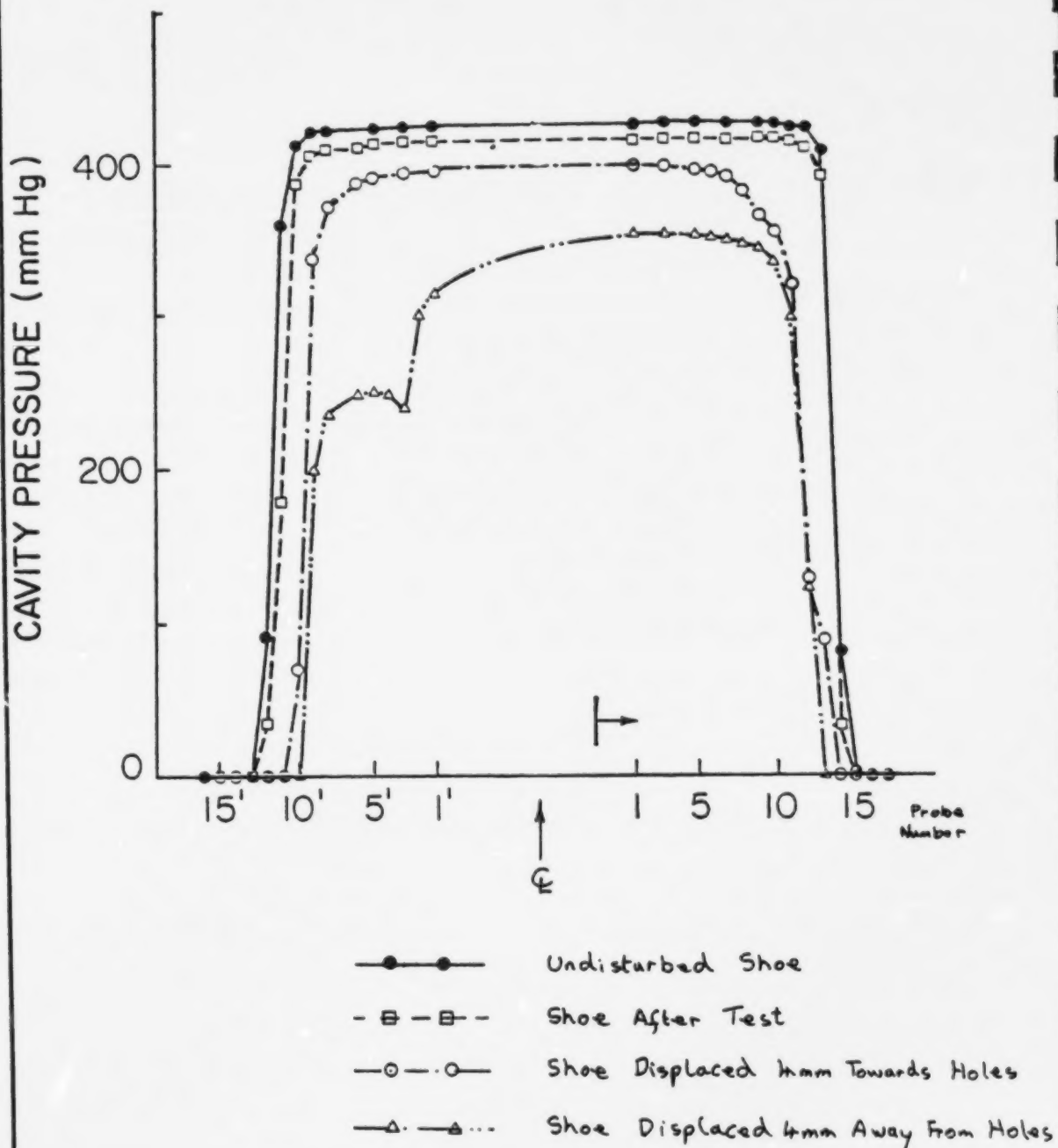


FIGURE 1: PRESSURE DISTRIBUTION UNDER SHOE



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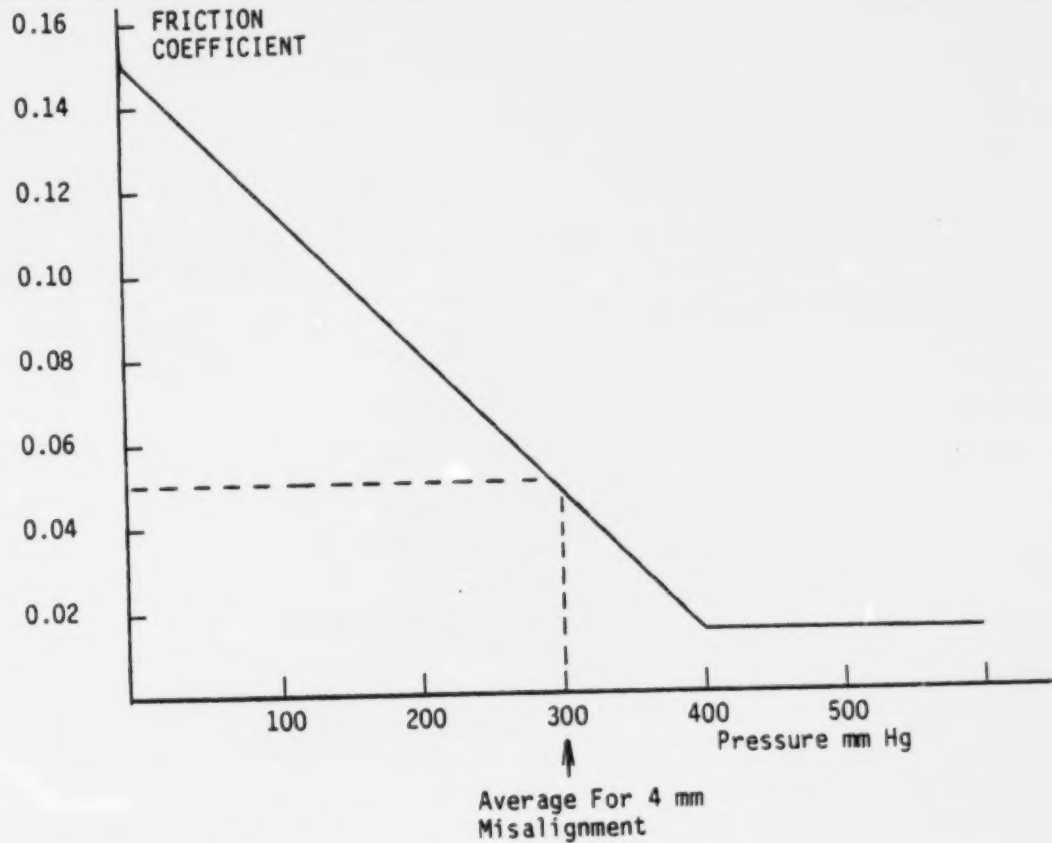


FIGURE 2: RELATIONSHIP OF AIR LIFT TO FRICTION (Long Shoe)

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2.2.2 Straight Line Friction

The development work carried out by the University of Toronto Institute for Aerospace Studies (UTIAS) has revealed the cellular nature of the lift under the shoe. At each end of the shoe the pressure is non-uniform and tends to zero at the exposed edge. For "interior" cells bounded by air injection holes the pressure and thus lift is considered uniform. As the shoe moves down the track, the end regions vary as a proportion of the overall length of the shoe depending on the relative position of air jets to shoe end. We can however, average the lift, and hence resulting drag, using the following assumptions:

- o Drag for no air is the dry coefficient of friction, typically 0.15, end cells have this value.
- o Drag for a uniform cell is 10% of this value typically 0.015.

This results in the following expression:

$$K_f = (0.1 \times k_{dry}) + \frac{((L \times n - 1) \times 0.1 \times k_{dry} + 1 \times k_{dry})}{2.0}$$

where K_{dry} = Dry Coefficient of Friction

L = Shoe length in metres

n = No. of holes per metre of Track

The results are calculated in Table 1 for Imperial unit track, i.e. 2 holes/ft, 3 holes/ft etc.



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The above expression can be re-arranged and simplified to yield:

$$K_f = K_{dry} (0.1 + 0.45/L \times n)$$

The results are plotted for $K_{dry} = 0.15$ in Figure 3

2.3

CURVING CAPABILITY OF STANDARD SHOES

The shoe is considered to be rigid in bulk, with local deflection where heavy contact is experienced. Thus a shoe contacts the curved rail at the centre on the inside of the rail and at both ends at the outside of the rail. This results in the following:

- o A loss of lift, and hence increase in drag due to non-uniform gap, and hence non-uniform pressure distribution.
- o A "squeeze" effect on the shoe material caused by the straight shoe being force fitted into the curved track. This locally overcomes air bearing action causing high local friction.
- o Distortion of the vehicle suspension geometry in the curve allowing side forces on the shoes. These are reacted by direct rail contact rather than air bearing action.
- o Centrifugal forces are reacted as above.

An "order-of-magnitude" analysis follows.



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K dry	Shoe Length	K _f		
	Ft	2 Holes/Ft	3 holes/Ft	4 Holes/Ft
0.15	1.0	0.0488	0.0375	0.0319
	1.5	0.0375	0.0300	0.0263
	2.0	0.0319	0.0263	0.0234
	3.0	0.0263	0.0225	0.0206
	4.0	0.0234	0.0206	0.0192
	6.0	0.0206	0.0188	0.0178
	8.0	0.0192	0.0178	0.0171
	∞	0.0150	0.0150	0.0150
0.18	1.0	0.0585	0.0450	0.0383
	1.5	0.0450	0.0360	0.0316
	2.0	0.0383	0.0316	0.0281
	3.0	0.0315	0.0270	0.0248
	4.0	0.0281	0.0248	0.0230
	6.0	0.0248	0.0226	0.0214
	8.0	0.0231	0.0214	0.0205
	∞	0.0180	0.0180	0.0180

TABLE 1: STRAIGHT LINE FRICTION
K_{dry} = 0.15 and 0.18



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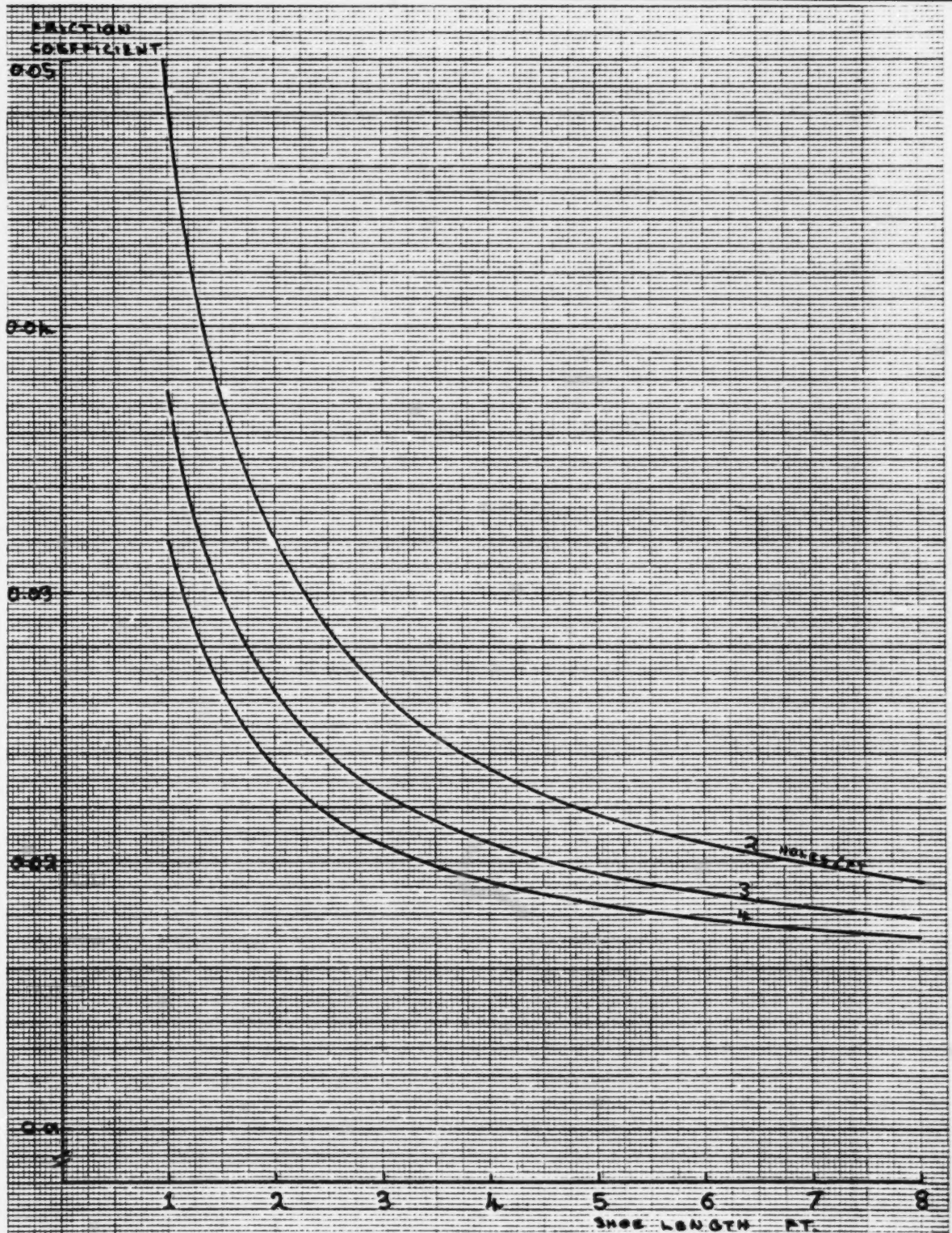


FIGURE 3: STRAIGHT LINE FRICTION AS A FUNCTION
OF TRACK GEOMETRY



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2.3.1 Loss of Lift

Very approximately the loss of lift is taken to be proportional to the lateral gap between shoe and rail. For shoe of length h and curve of radius R , this gap h at the centre of the shoe is given by:

$$h = \frac{L^2}{8R}$$

The average gap along the shoe is taken to be half this value ($L^2/16R$) and from Figure 2 we can estimate the increase in friction for an average value of misalignment of 4 mm to be from a baseline of 0.015 to a value of 0.05.

$$\Delta K_f / \Delta h = \frac{0.035}{0.004} = 8.75$$

For 0.6 m (24 inch) shoes on a 20 m curve this extra friction due to loss of lift would be 0.01.

2.3.2 Squeeze Effect

The pressure distribution under the shoe is plotted in Figure 1. It does not extend very far up the sides of the curved rail, and therefore ability to support side loads is limited to approximately 3.6 N/cm of shoe by virtue of the lateral component of air pressure (See Figure 4). In the curving case this air pressure profile is particularly disturbed, and pressure reduced near the sides, thus drastically reducing air bearing action in these regions. It is concluded that the squeeze effect on the shoe is totally reacted by shoe/rail contact, resulting in increased



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friction. Clearly the forces are proportional to the deflection, assuming that the shoe is linearly elastic for small deflections, then 'squeeze' friction forces are again proportional to L^2/R .

A 0.6 m shoe has a vertical stiffness of approximately 1000 lb/in (180,000 N/m) and a horizontal stiffness which is of the same order of magnitude or larger.

In a curve of radius 20 m with 0.6 in shoes we are attempting to deform the shoe by 2.25 mm, this will require a force of approximately 400 N, and since the air film is broken down, a fraction (15%) of this or 60 N will result. The maximum load supported by the deformed shoe is of order 1,250 N, therefore the effective increase in friction coefficient due to 'squeeze' effect is thus:

$$K_s = \frac{60}{1250} = 0.048$$

i.e. 4.8 times larger than increased friction due to loss of lift!!!

2.3.3 Suspension Distortion

To avoid friction effects of similar magnitude to the squeeze effects looked at in 2.3.2 it is an advantage to avoid misalignment between the bulk of the shoe and the rail. A completely floating shoe would avoid this effect. At the opposite extreme a 2 m long vehicle with rigidly mounted short shoes at each end clearly will have shoes misaligned with the rail by an amount proportional to the vehicle length squared, rather than shoe length squared. This effect is vehicle design specific and is not examined further.

2.3.4 Summary of Friction Effects

The increased friction is proportional to shoe length squared divided by curve radius. For our example of 0.6 m shoes on a 20 m curve the increase over straight line friction is of order 0.058 resulting in a total of $0.032 + 0.058 = 0.09$ on track with 2 holes per foot.

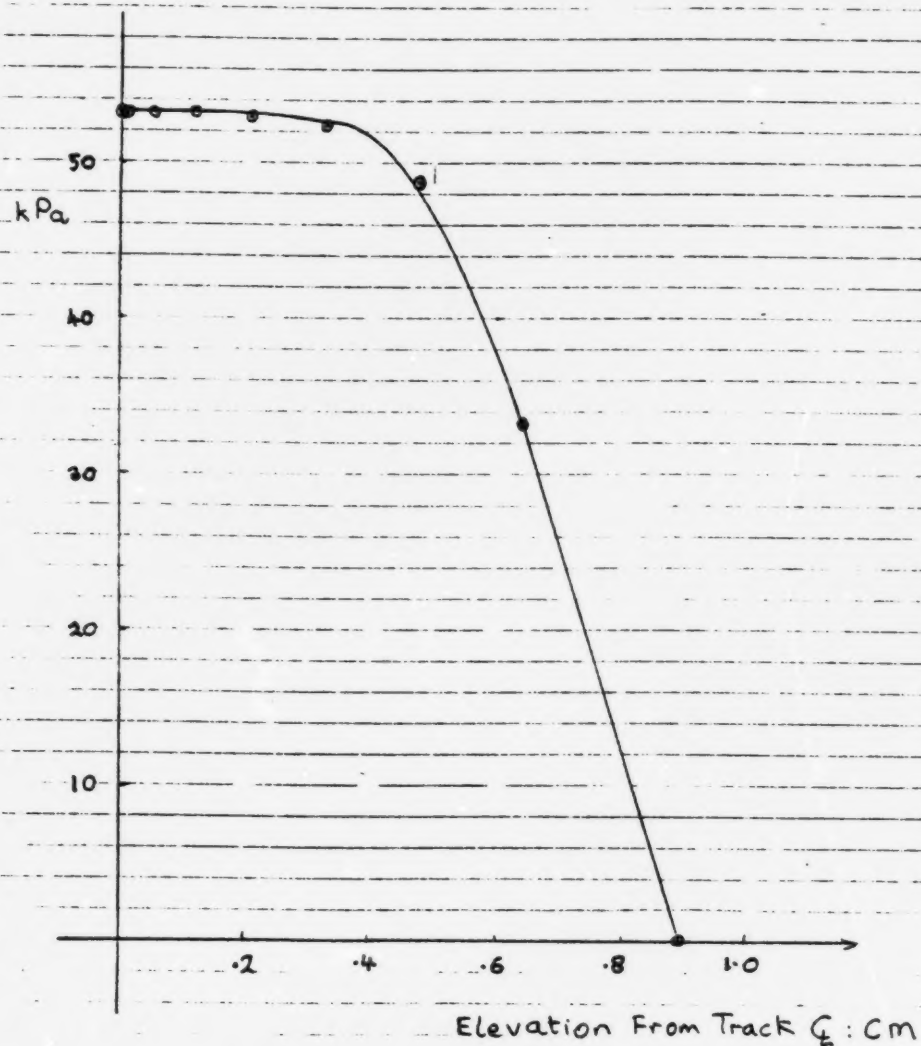


FIGURE 4. LATERAL COMPONENT OF PRESSURE

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3.0

ANALYSIS OF TEST DATA

3.1

INTRODUCTION

Simple friction measurements were made by towing the Engineering Test Vehicles and a smaller 0.6 m long car with only two shoes, with a force gauge for a variety of test conditions. Effects investigated included:

- o Vehicle weight
- o Shoe length
- o Shoe diameter
- o Air pressure
- o Air hole location and number
- o Track conditions
- o Anodised versus Non-Anodized Rail
- o Suspension type

Factors which were found to greatly influence the results, but not originally intended to be test variables, were the weather and degree of rail distortion.

3.2

TEST SET-UP

The test was carried out using the procedure given in Ref. 2. Approximately 7.5 m of straight rail and 30 m of curves equally right and left handed were used. The track layout is shown in Figure 5. The principle factor that affected all test results was the distortion of the curved rail. The rail was permanently deformed into the required curves by a rolling process. This resulted in a crushing of the rail into a profile similar to that shown in Fig. 6. The effect is discussed in a later section.



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3.3 TEST RESULTS

The test results in raw form are given in Appendix 7.1. Friction coefficients are calculated in the test result tables in Appendix 7.1. As a general comment it can be concluded that there was a great deal of scatter in the results, and all values are typically $\pm 20\%$. However a general pattern soon emerged from the tests summarized below:

- o The test results at all configurations, air pressures and weather conditions showed a similar profile. Friction was always lowest in the first segment C1 of the curved rail. This section also had the lowest degree of distortion.
- o Friction coefficients varied from a high of 0.16 (ie. no airbearing action at all) to a low of 0.077 for very short shoes at high air pressure in the best Curve C1.
- o The unanodised rail consistently resulted in higher friction levels than anodised rail. A greyish powder accumulated on the rail (presumably Aluminum Oxide) and dry (or airless) friction coefficient jumped from 0.15 to 0.25.
- o Carefully cleaning and polishing the track would reduce friction coefficient by 0.03 for most test configurations. A water spray had the same result as long as the track was very wet.
- o The shoes were visibly squeezed and distorted, not only by the curve, but also by the rail distortion. This effect was noticeably less in C1.
- o Friction was reduced by reducing the length.



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- o Further small improvements were made by reducing shoe diameter in an attempt to match new rail profile. Shoes were reduced in circumference from an initial 15.5" to 14.75" and then 13.25".
- o All efforts to reduce curving friction resulted in increased straight line friction. For example 18" long shoes with 13.25" circumference gave a straight line friction of 0.06!!
- o Air pressure and hole pattern had small effects.

The boundary of test results and the effect of changes made is shown in Figure 7. It was concluded that the distorted rail caused most of the increase in friction over the expected values, which as calculated in the previous section might be as high as 0.09. However the initial shoe deflection due to squeeze had been expected to be softer, or non-linear, therefore it had been hoped that friction coefficients as low as 0.06 might result.

The rail profiles were measured with a profile gauge and are included as Appendix 7.2. By comparing the profiles with the undistorted shape for curves C1 and C2 and totalling the accuracy of profile by square counting the area under the profile a measure of fit in percent was derived. In Figure 8 a wide variety of test results for 0.45 and 0.6 m shoes is plotted against % fit and extrapolated to a 100% fit (or undistorted) value. This results in an average friction coefficient for 20 m curves of 0.085. It is notable that the best single run values obtained with reduced crossection shoes were in the 0.077 to 0.09 region.



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The raw results can further be corrected for angle of pulling rope (approx 25°) and a dry coefficient of friction of 0.18 versus the 0.15 which is achieved with a well polished track after several weeks operation.

$$K_T \text{ corrected} = 0.085 \times \frac{0.15}{0.18} \times \cos 25^\circ = 0.065$$

From the above test series it was concluded that operation of the Transporter Vehicle with 0.6 m shoes on 20 m curves would result in a friction coefficient of 0.065 for clean dry rail and an air pressure of 15 psig at vehicle weights of 170 to 500 kg.



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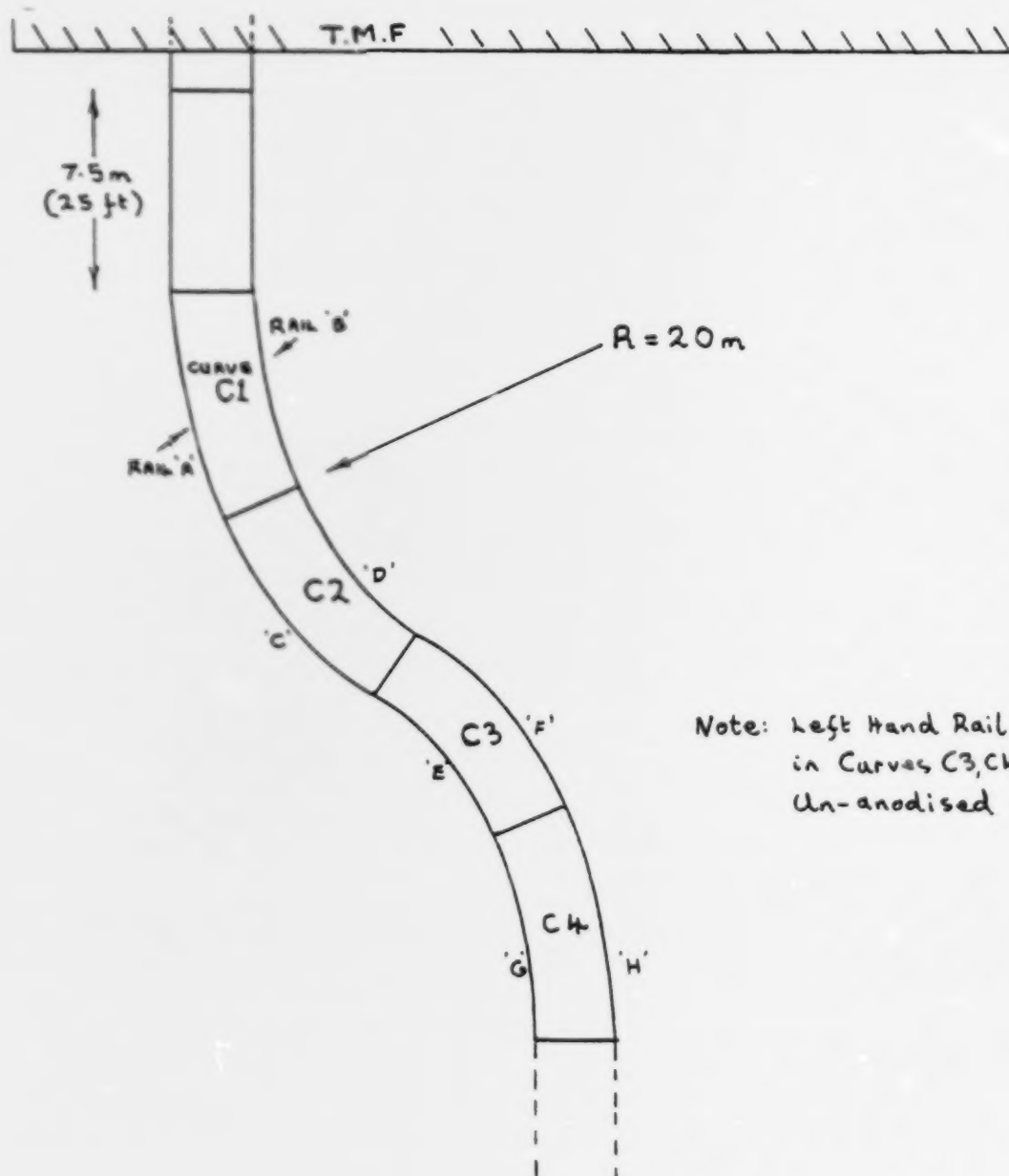


FIGURE 5: TRACK LAYOUT



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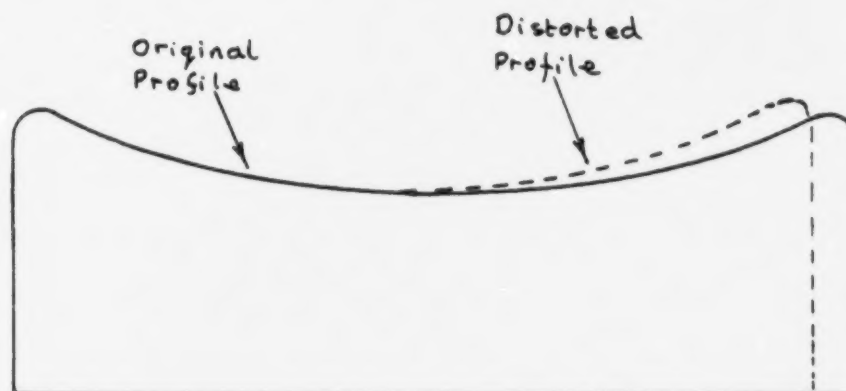


FIGURE 6: RAIL DISTORTION CAUSED BY ROLLING OPERATION



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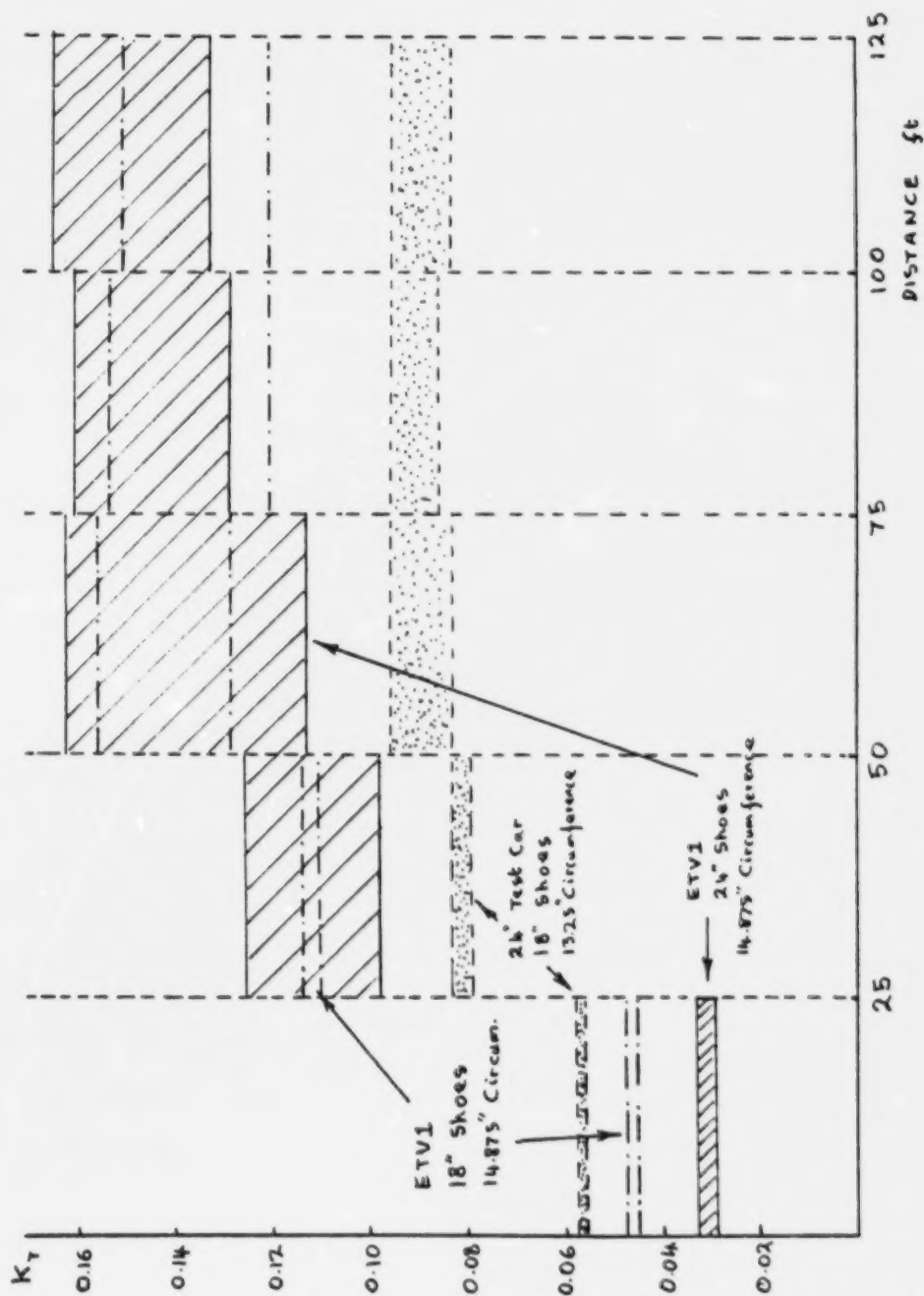


FIGURE 7: FRICTION TEST RESULTS

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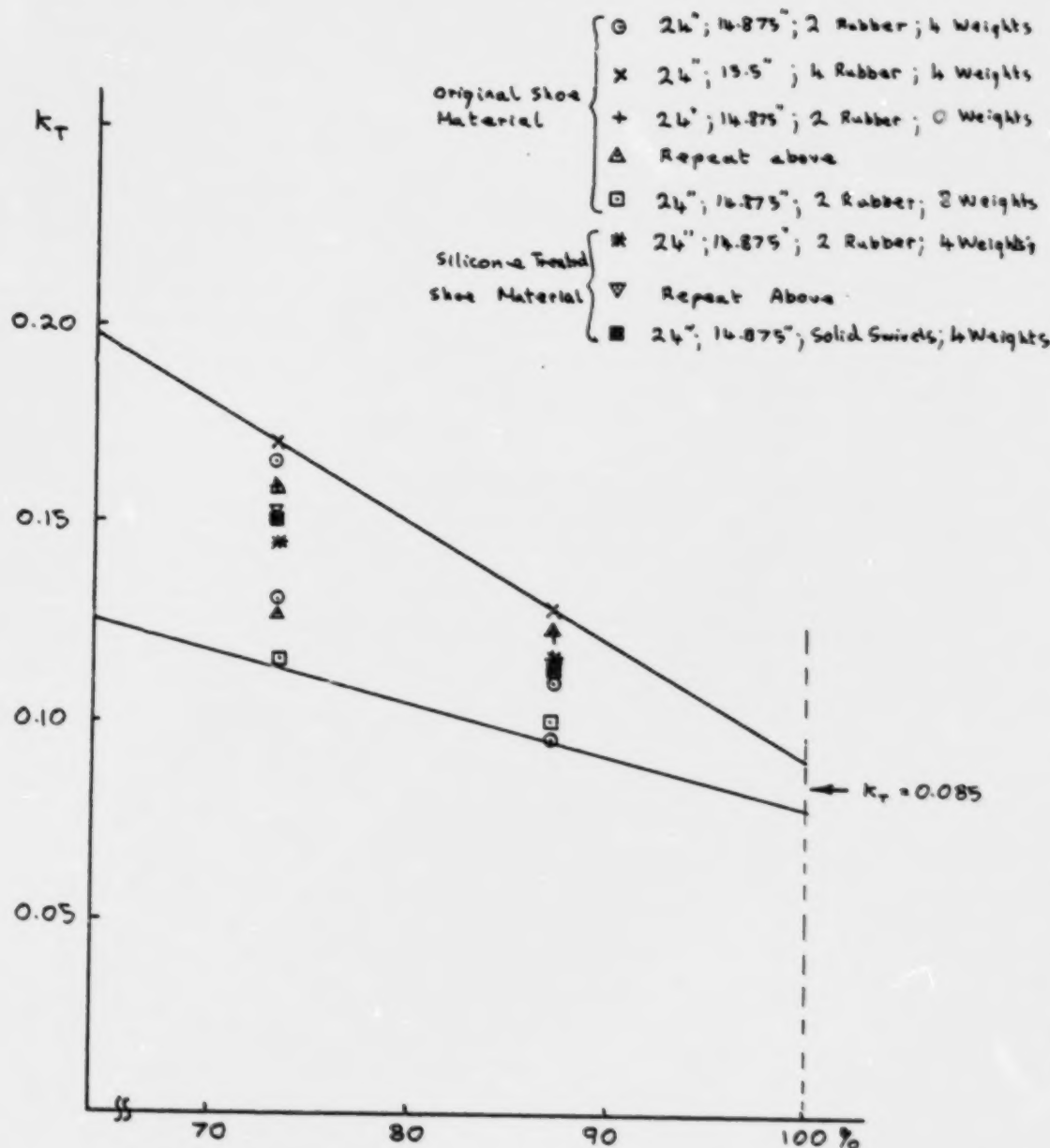


FIGURE 8: EXTRAPOLATION TO ZERO DISTORTION RESULTS



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GENERALIZED RESULTS

For each combination of shoe length and curvature there will be a total friction coefficient resulting from the combined effects of straight line friction (which as was shown earlier depends on shoe length, hole pattern and dry friction coefficient) and a curving term which is proportional to the square of shoe length and inversely proportional to radius of curvature i.e:

$$K_T = K_C + K_F$$

For 0.6 m shoes on straight track with 2 holes/ft

$$K_F = 0.032$$

$$\text{and } K_C = 0.065 - 0.032 = 0.033$$

To generalize for other conditions

$$(K_C)_i = 0.033 \times \frac{L_i}{0.6}^2 \times \frac{20.0}{R_i}$$

The generalized levels for various radii of track and shoe length are calculated in Table 2 and plotted in Figure 9.



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Shoe Length M	Curve Radius M	∞ Kf	200		100		80		60		40		20	
			Kc	Kt	Kc	Kt	Kc	Kt	Kc	Kt	Kc	Kt	Kc	Kt
kdry =0.15	0.3	0.049	.001	.050	.002	.051	0.002	0.051	0.003	0.052	.004	.053	.008	.057
	0.6	0.032	.003	.035	.007	.039	0.008	0.040	0.011	0.043	.017	.049	.033	.065
	0.9	0.026	.007	.033	.015	.041	0.019	0.045	0.025	0.051	.037	.063	.074	.100
	1.2	0.023	.013	.036	.026	.049	0.033	0.056	0.044	0.067	.066	.089	.132	.155 (.150)
	1.8	0.021	.030	.051	.059	.080	0.074	0.095	0.099	0.120	.149	.170 (.150)	-	.150
	2.4	0.019	.053	.072	.106	.125	0.132	0.151	0.176	0.195 (.150)	-	.150	-	.150
kdry =0.18	0.3	0.059		.060		.061		0.061		0.062		.064		.068
	0.6	0.038		.042		.047		0.048		0.052		.059		.078
	0.9	0.031		.040		.049		0.054		0.061		.076		.120
	1.2	0.028		.043		.059		0.067		0.080		.107		.180
	1.8	0.025		.061		.096		0.114		0.144		.180		.180
	2.4	0.023		.086		.150		0.182		0.180		.180		.180

TABLE 2: CALCULATION OF CURVING FRICTION



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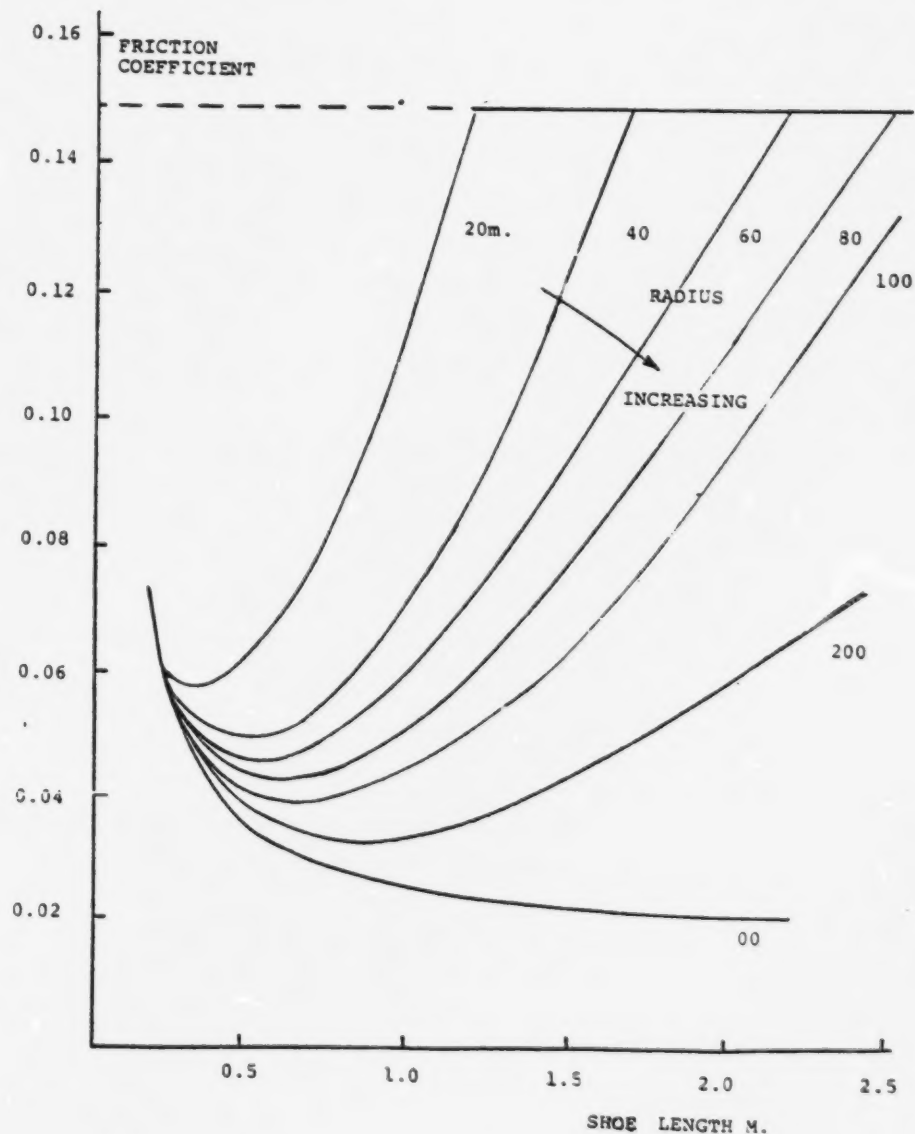


FIGURE 9: VARIATION OF CURVING FRICTION WITH SHOE LENGTH AND CURVE RADIUS



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CONCLUSIONS AND RECOMMENDATIONS

It can be concluded from the rather crude and approximate theories and test results presented in this report that:

- o Curving friction is proportional to shoe length squared and inversely proportional to curve radius.
- o In order to achieve low friction in curves it is necessary to articulate the shoes in yaw, but they must be stiff in roll to resist overturning.
- o With existing shoe and suspension technology it is necessary to limit minimum curve radius to a value in the 60 to 80 m region in order to limit friction to manageable levels of 0.045 to 0.055.
- o Switch designs might be achieved with much smaller radii, of order 20 m, while providing extra LIM's to overcome friction levels of at least 0.065 with 0.6 m shoes.

It is recommended that this analysis form the basis of track design for the demonstration, and that allowances of 50% should be used in selecting LIM's.



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TRANSPORTER
ALL WEATHER OPERATION
EXPANSION JOINT DESIGN



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SUMMARY

All weather rail expansion joint requirements are studied and a recommended design is shown in concept. Air supply concepts are also shown. It is concluded that individual rail sections, plugged at each end, with slip joint provisions, and with individual air supply and control are most viable for the requirements of a short run transporter. The requirement for leak-proof air joints is attainable.



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OBJECTIVE

In reviewing possible techniques for all weather operation, a rail joint design is required.



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BACKGROUND

Previous rail joint designs using continuous flow-through of air under pressure, and epoxy sealed joints, proved to be unsatisfactory for all weather operations due to the expansion and contraction of the rails at the joint spurs. It was found that a movement of approximately one millimeter for every degree celsius change in ambient temperature was possible, for 40 metres of rail.



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3.0 TASK

Design a sealed joint that is independent of rail expansion and contraction but which may be held in alignment and be used for storage and dispersement of air under pressure.

3.1 METHOD OF SEALING

Using shortened and plugged (or undrilled) spurs provided for rail containment and alignment weld (gas tight) plugs into each rail end so that slip joint spurs may be inserted to ensure proper rail alignment. Figure 1 illustrates the concept. (Ref. Drawing No. 68-401-014). A test piece was welded to ensure viability of the concept. The surface of the rail remained undisturbed and the welds are leak tight.

3.2 AIR SUPPLY

Provision for air supply is as previously designed and this is illustrated in Figure 2 (Drawing No. 68-401-016 refers), with alternate systems or interconnections shown in Figure 3, and Figure 4 where on/off control of the air supply is required. Drawing No. 68-401-017 and Drawing No. 68-401-018 provide details.

All air valves, solenoids and interconnects must be "all-weather" tolerant and capable of accepting heated air, i.e., higher than ambient, provided through the air compressor supply system at a temperature of up to 80°C.



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CONCLUSION

An all-weather, leak tight, rail expansion joint has been provided and air supply control to each sealed section of rail is considered. Illustrated concepts are provided and a weld test piece has proven the concept.



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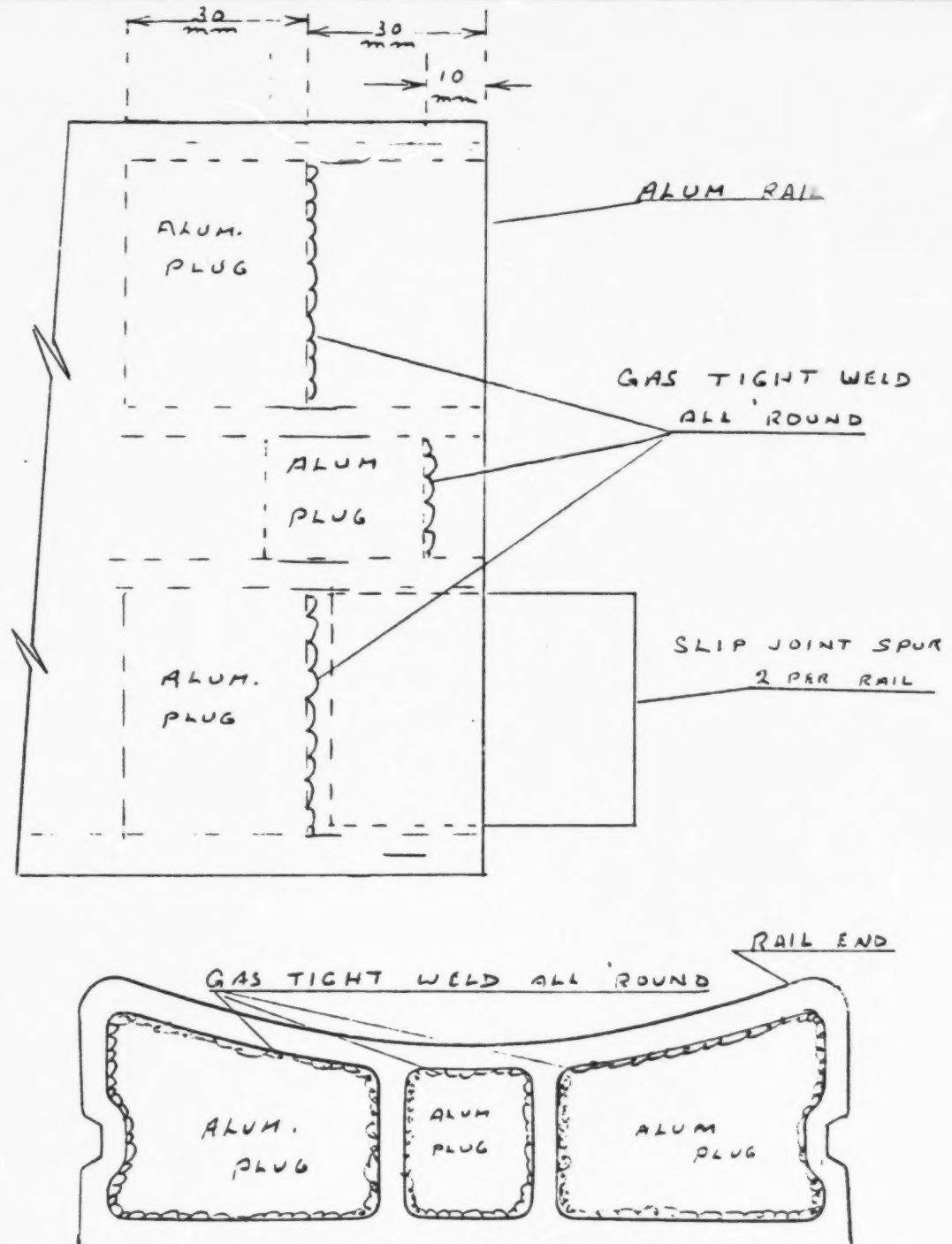


FIGURE 1

ALL WEATHER EXPANSION JOINT

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SCALE: Full Size

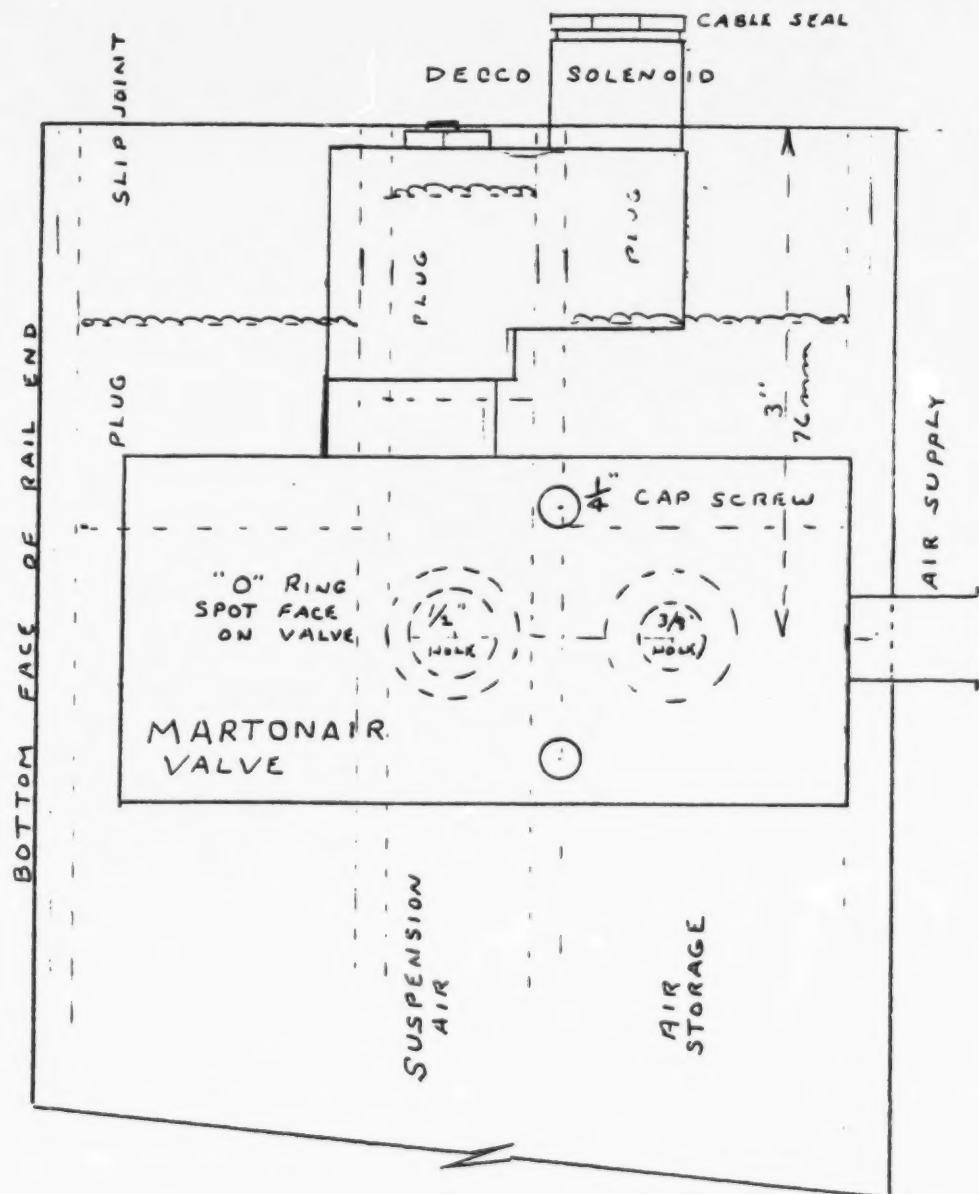


FIGURE 2
AIR CONTROL



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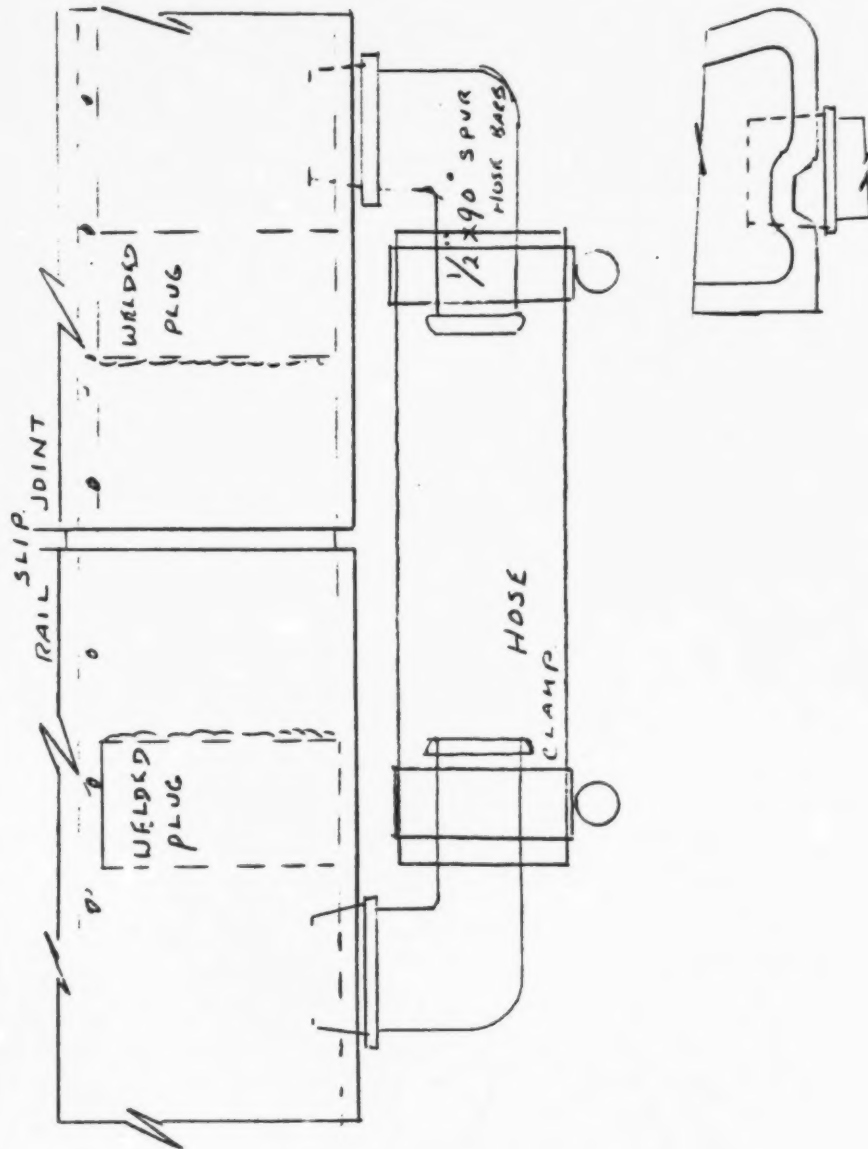
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SCALE: FULL SIZE

FIG 3

AIR INTERCONNECT FOR JOINTED RAIL SECTIONS.

FIGURE 3

AIR INTERCONNECT FOR JOINTED RAIL SECTIONS



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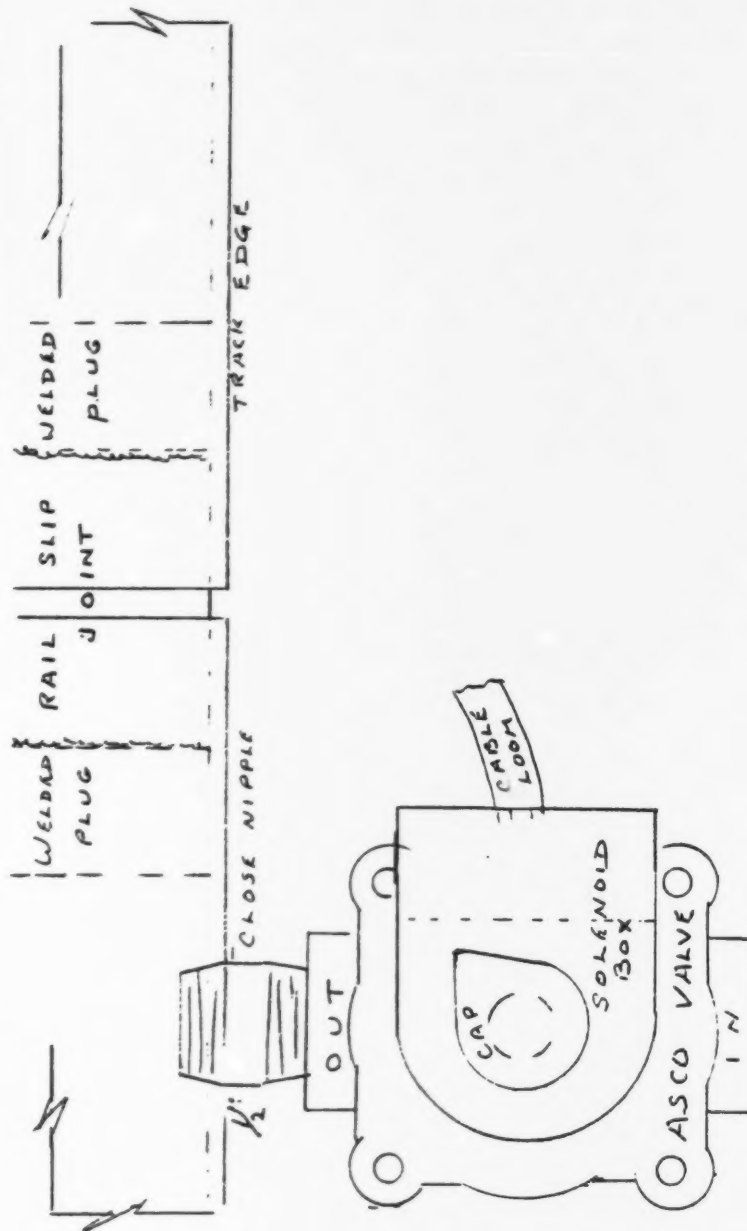
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SCALE = FULL SIZE

ALTERNATE

AIR SUPPLY TO TRACK MANIFOLD

FIGURE 4

ALTERNATE AIR SUPPLY CONTROL

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TRACK DE-ICING SYSTEM

Project Engineer

S. Gamm

Project Manager

W. B. Ceppi



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SUMMARY

The requirements of the track de-icing system are reviewed and competing system concepts evaluated. A hot-air system was selected for installation and testing with a required power level of 8 to 10 kW. The system will require compressor operation.



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PURPOSE

The purpose of the task is to review the operational requirements of the track de-icing system and select a viable and cost-effective system for installation and test on the 40 m track.



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OPERATING REQUIREMENT

The winter conditions at the Kingston test site include a 97.5% chance of -24°C temperatures and annual precipitation of 0.96 m of rain and rain equivalent of snow. (Refs 1 and 2) During the months of January, February and March a snow cover of 0.2 m is expected on average. The system must be designed to operate with a minimum of disruption in all but the most severe storms and a minimum of labour.



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CONCEPT REVIEW

The track slabs has been designed to present a flush surface which can be easily cleaned of snow and ice by mechanical means such as snow-blower, leaving only a thin layer of compacted snow or ice expected to be no more than 6 mm thick.

A number of means of removing the remaining ice are considered below. The review is restricted to the track running rails, since both sensors and LIM's will operate satisfactorily through 6 mm of ice.

- o Chemical de-icing is used on sidewalks and roadways. It is rejected for Transporter based on the certainty of corrosion to the aluminum rails, and possible damage to sensors, LIM's and wiring.
- o Radiant heat or direct flame de-icing is rejected based on the erratic and labour-intensive nature of the heating. Damage to plastic parts and rail distortion might be caused.
- o Plate-type electric resistance heaters can be bolted to the rails but are expensive per unit and generally run at higher temperatures and power outputs than required. In order to use plate heaters they would have to be widely spaced, resulting in uneven heating. They are thus not selected for use.
- o Heat trace cable is used to keep pipe systems from freezing and is both flexible and of low cost. It does not, however, provide sufficient heat to de-ice large surfaces.



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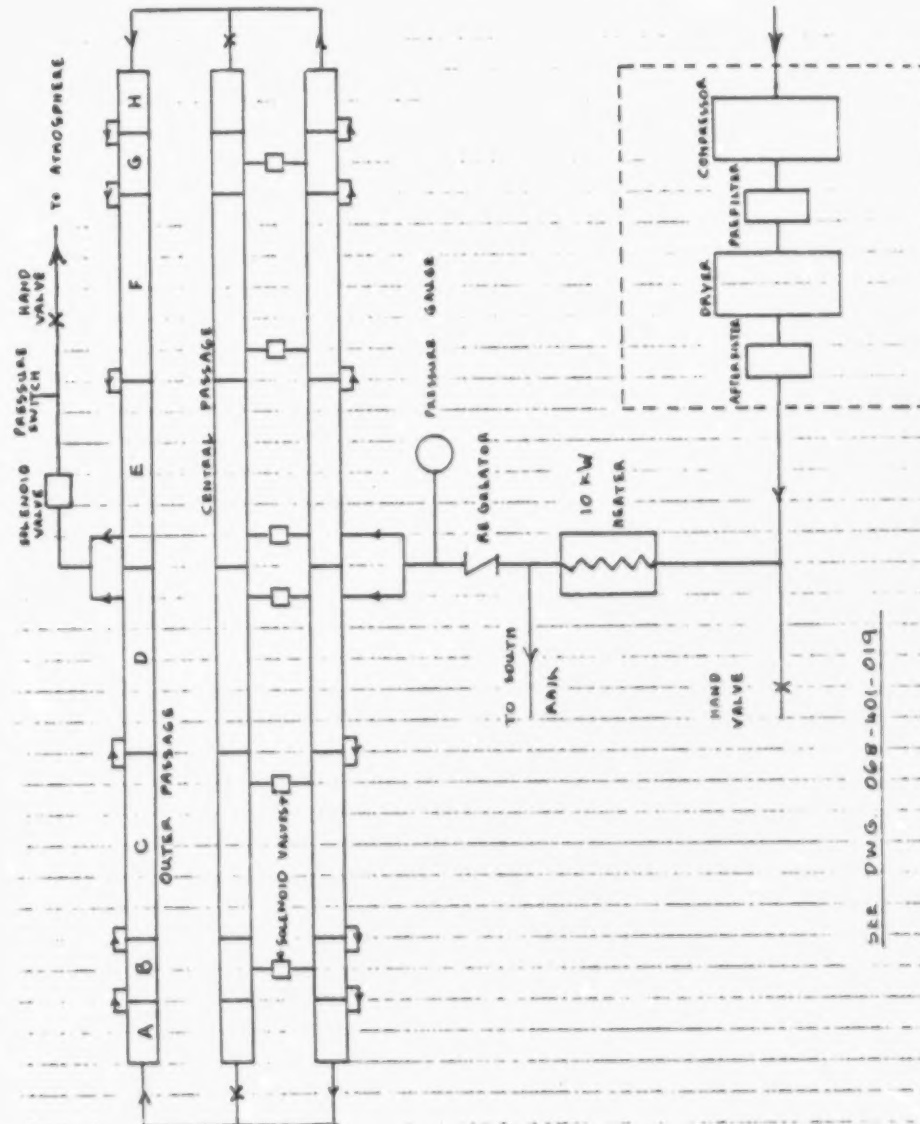
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- o Flat parallel-element heating cable is available with suitable heating rates but not currently available in the width required for the transporter rails. Based on simple installation and low costs this concept should be examined for any production installation, but custom-designed element is unlikely to be available with a lead time of a few weeks. The heating film used on ICTS power rails is of similar interest for commercial installations, but currently has a heating rate of 30 watts/ft² (3).
- o Hydronic heating systems (Ref 4, 5) are frequently used for large surfaces such as patios and vehicle ramps. Installation costs are lower than buried resistance cable for large areas, but a small installation would be unlikely to be cost effective. (Hydronic systems circulate heated glycol-water mixture through small bore plastic embedded piping).

After the above review it was concluded that it would be best to heat the air in the track. This is achieved by placing an electric resistance heater in the piping from the compressor and circulating the air around the outer passages of the rail. This will not only de-ice the rail surface, but also the rail centre passage if blocked by ice.

The proposed system is shown in Figure 1.



SEE DWG. 06B-401-019

FIGURE 1: HOT-AIR DE-ICING SYSTEM



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4.0 SYSTEM DESIGN

4.1 OVERALL HEATING REQUIREMENTS

The rail when embedded will have a total exposed surface area of 110 sq. ft. Based on a review of several references (6, 7) it was concluded that a surface heating of 60 w/sq. ft. is sufficient to both melt snow and ice accumulations, and keep the surface clear. Thus minimum system capacity is $110 \times 60 = 6.6$ kW. In order to allow for system losses and heat loss sideways and downwards an increase of 25 to 50% should be provided resulting in an air heater requirement in the 8 to 10 kW range.

4.2 TIME TO MELT ICE

In the worst case the rail trough and central passage will be solid ice. For 40 m of two rails with an ice cross-section of 0.0013 m^2 the total volume is 0.104 m^3 or 104 kg of ice. Based on supplying only the latent heat of fusion (333.3 KJ/Kg) a total amount of heat to be supplied is $104 \times 333.3 = 34663$ KJ. At the minimum system capacity of 6.6 kW (6.6 KJ/sec) the ice will take $34663.2/6.6 = 5252$ seconds or 1.46 hrs to melt. For a worst case this is acceptable.

4.3 CONTROL CONSIDERATIONS

For present purposes, which are to demonstrate feasibility and ensure operation, a simple thermostat is required to limit air temperature below that which would cause excessive rail expansion or damage solenoid valve seats and plastic jumper tubing between rail sections. The heater must also be



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protected from a zero flow condition by an interlock with both compressor operation and the discharge solenoid valve shown in Figure 1.

A thermostat setting of approximately 150°F/65°C should be used at first while monitoring rail temperature and expansion.



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CONCLUSIONS AND RECOMMENDATIONS

Based on a brief review of snow and ice melting requirements and concepts, a hot-air system of capacity in the range 8 to 10 kW is selected. The system will heat the air incoming from the compressor before circulating around the outer rail passages and being vented overboard. The major disadvantage of the system is the requirement of compressor operation.

Interlocks are recommended to prevent burn-out of the heater under zero-flow conditions.



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SUMMARY

The presented Control Concept will be an intermediate stage in a final control system. This option is based on centrally powered and controlled LIMs. One frequency converter will be distributed with power contactors. Logic will be implemented by a small Programmable Logic Controller.



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CRITERIA AND ASSUMPTIONS

This option is based on the following criteria:

- o to be an intermediate stage in the development of the final optimum and advanced system
- o Cost limitation
- o Fixed time frame

Main assumptions of the concept are the following:

- o Centrally powered and controlled LIMs
- o Inductive proximity sensors one per LIM
- o Logic implemented by PLC
- o Small hard logic, displays, switches and set points implemented in Control Panel



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2.0

ARCHITECTURE OF THE CONTROL SYSTEM

Shown in Figure 1.

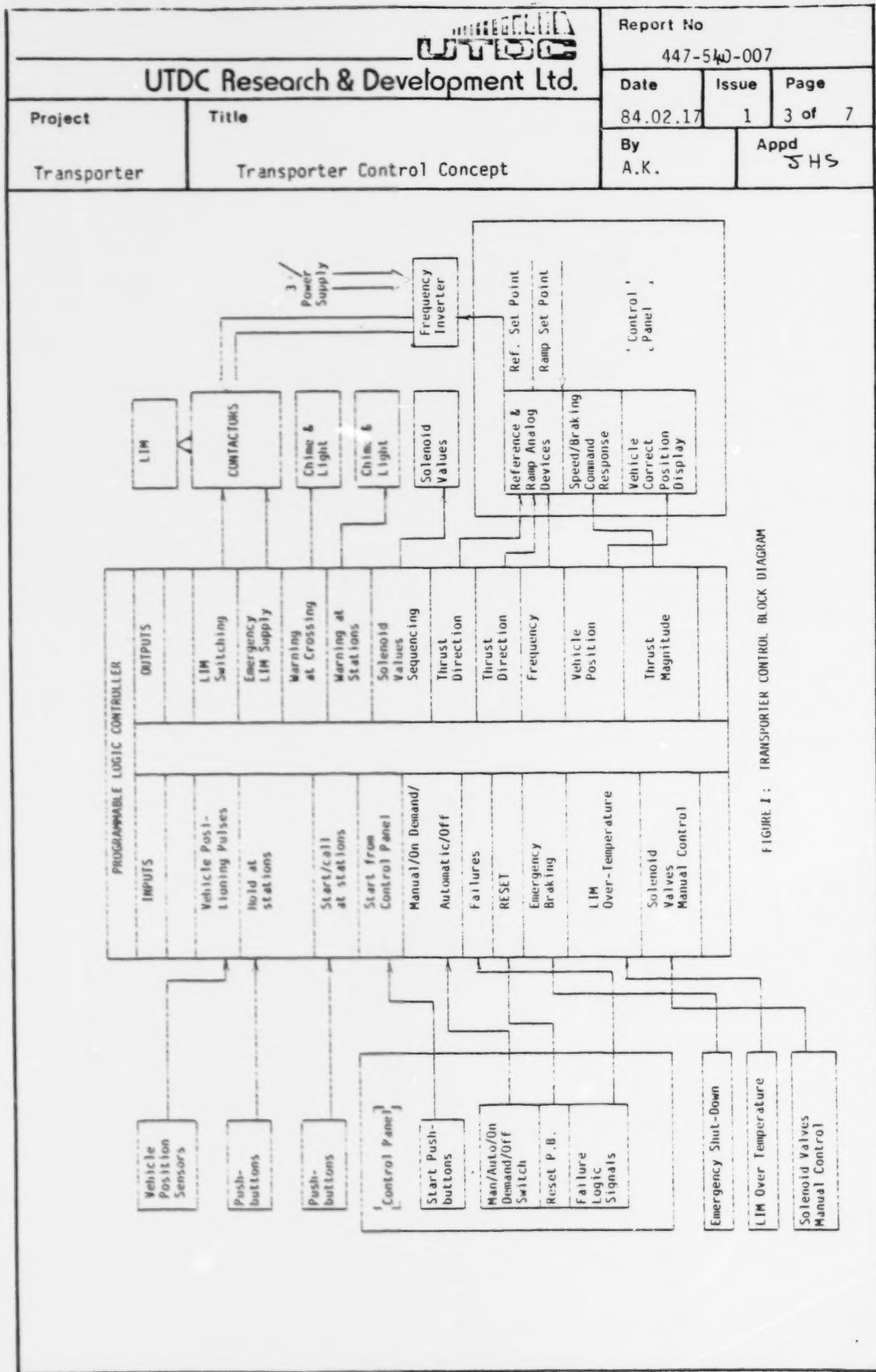


FIGURE 1 : TRANSPORTER CONTROL BLOCK DIAGRAM



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MAIN HARDWARE IMPLEMENTATION

Main Hardware Implementation is as follows:

- o One frequency inverter distributed with power contactors
- o Small PLC with 62 I/O and memory size up to 1 k words.

PLC should be one of the following models:

- from Texas Instruments: TI520 or 5T1
- from Allen Bradley: Mini-PLC-2
- from Modicon: Model 484
- o Control Panel designed and built by R&D, implemented following functions:
 - Signal of failures such as:
 - Power supply
 - Frequency controller (overloading)
 - Air pressure
 - LIM's overheating
 - Vehicle's stopping on truck
 - Emergency Shut Down (function & signalization)



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- Displaying of Vehicle Position
- Manual Automatic Switching
- Start/stop operating, manual and automatic
- Set Point for analog reference voltage for frequency controller
- Reset Failures' signalization



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MAIN FEATURES OF THE CONCEPT

- o Non controlled prefixed maximum frequency of the frequency controller so maximum speed will be controlled in passive manner.
- o Prefixed analog reference voltage (ramp) for acceleration and deceleration
- o Ten pulses from each proximity sensor per whole length of the vehicle, so the position of the vehicle could be determined with the accuracy ± 10 cm on cruise and ± 5 cm on acc/braking zone.
- o Logic implemented by PLC
 - Wait time before starting (after getting start signal) and announcement signal
 - Acceleration and Braking control
 - Switching of LIMs
 - Stopping in station
 - Overspeed control
 - Calling from another station
 - Stopping on track if requirement or in case of failure
 - Restart after stopping on track or after emergency shut down



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- Emergency braking after overpassing external position
- Emergency braking after failure of the frequency controller on braking
- Manual/Automatic operating
- Warning at crossing
- o Logic implemented by control panel
 - Emergency shut down
 - Failure signalization
 - Failure signal for PLC

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VEHICLE OPERATION DESCRIPTION

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Date: 84.03.16

Prepared by:

M. Alimji

Approved by:

J. Stander



UTDC Research & Development Ltd.

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SUMMARY

The requirements of the vehicle operation are reviewed. The vehicle operation system was selected and will be the basis for PLC programming.



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System operates as following:

1.0 CONTROL BOX AT STATIONS

1.1 SYSTEM READY LIGHT

- o Power on
- o Air on
- o No failure signals
- o Vehicle in right position

1.2 START/CALL PUSH BUTTON

- Operates when system is ready
- After pushing:
 - o count the 5 sec waiting time and gives the warning by:
 - o 5 chime sounds on both stations
 - o 5 light flashes on both stations
- After 5 sec elapsed
 - o vehicle start
 - o warnings at crossing operate (Chime, flashing light) (± 5 m to crossing center line)



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1.3 STOP PUSH BUTTON

- Operates anytime and on both stations after "start/call" Push Button is activated.
- After pushing the button:
 - o before "start/call" is pushed then nothing will happen;
 - o at the same time with "start/call" then nothing will happen;
 - o within 5 sec "warning time" "start" signal is cancelled and system remains ready;
 - o after vehicle is started, nothing will happen.

1.4 EMERGENCY PUSH BUTTON

- Operates anytime on both stations and at the crossing
- After pushing the button
 - o before vehicle started, system becomes "Not Ready" and remains without power.
 - o after vehicle started, emergency braking is activated and after stopping system remains "Not Ready".
 - o "Ready" can be activated from Control Panel after investigation and reset.

1.5 OUTLET 110 V (FOR GENERAL PURPOSE)

1.6 SPECIAL SWITCH FOR SERVICE PURPOSE



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2.0

WARNINGS OF CROSSING

Chime

Amber Flashing Light

- Operates always when vehicle is running within

± 5 m from crossing center line



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GENERAL

- After vehicle is stopped at the station 10 sec must elapse before the next start.
- Vehicle can be sent to another station without passengers.



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4.0 CONTROL PANEL MODES OF OPERATION

4.1 MANUAL OPERATION

- From control panel only
- Acceleration/Braking
- Speed variation possible
- Stop the vehicle at any time
- Start the vehicle from any position

4.2 "ON DEMAND" OPERATION

- From control box at stations only

4.3 AUTOMATED OPERATION

- Cycles automatically with 10 sec stopping at stations (5 sec waiting time and 5 sec warning time)
- Stop Push Button operates as following:
 - o Pushing after vehicle started, emergency braking is activated and after stopping system remains "Not Ready".
 - "Start" can be activated from control panel after "Reset".
 - o Pushing within 5 sec "warning time". 10 sec waiting time is added.

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MB

COMPRESSOR NOISE REDUCTION

Report No.: 447-550-007

Date: 84.02.18

Project Engineer

S. J. ...

Project Manager

M. Baygali



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Transporter

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HNB

SUMMARY

The compressor in untreated form radiates noise at a sound pressure level of 88.1 dBA at 1 m. A proprietary enclosure reduces this to 82.4 dBA. The noise reduction system discussed in this report will achieve the objective of 69 dBA at 5 m from the compressor hut.



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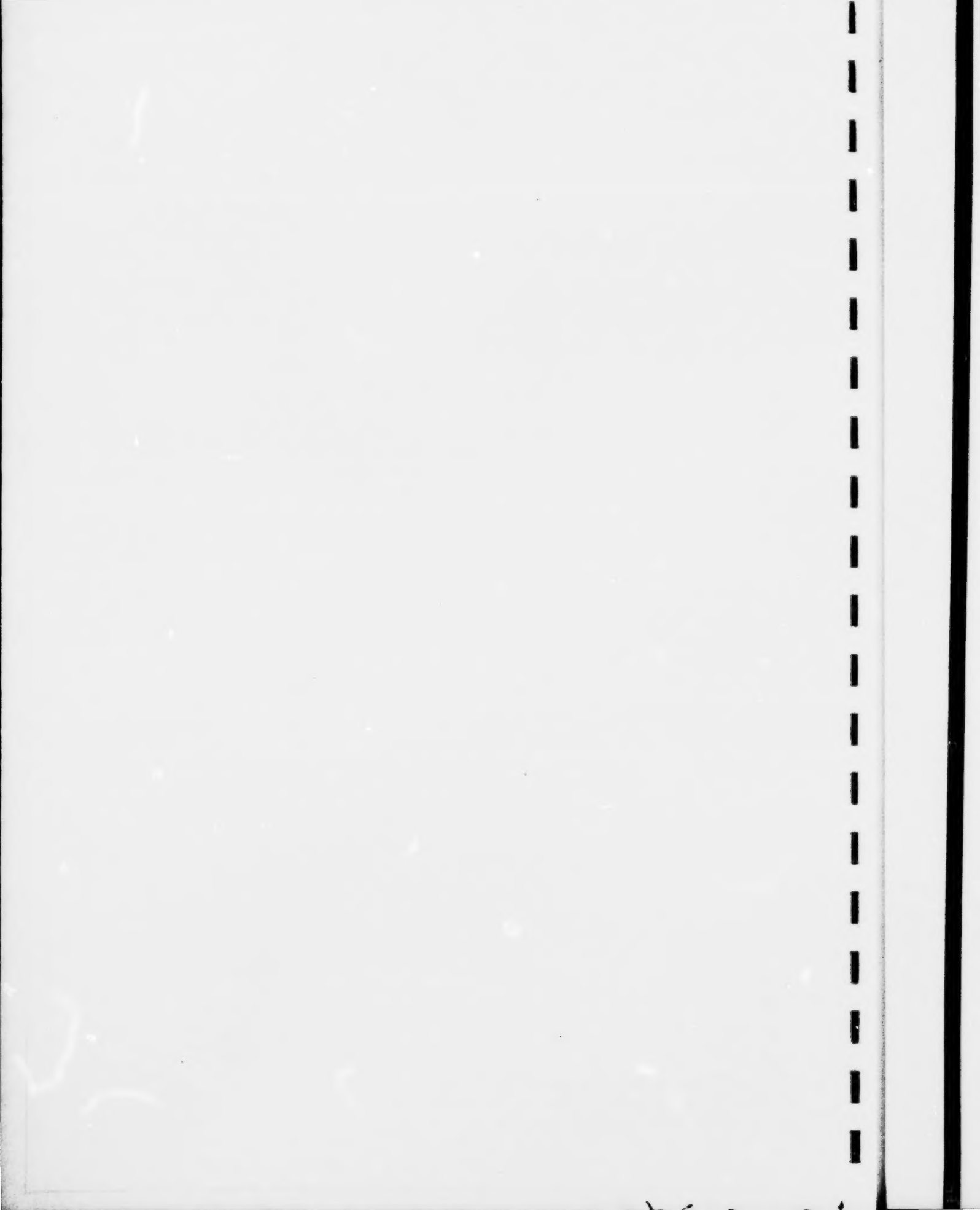
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PURPOSE

To determine the extent and nature of acoustic treatment required to reduce external noise from the Transporter air compressor to 69 dBA.



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Compressor Noise Reduction

2.0 CALCULATION

2.1 NOISE SPECTRUM

The untreated compressor radiates noise at an approximate sound pressure level of 88 dBA, which is reduced to approximately 83 dBA by a proprietary enclosure for the machine from the Suppliers, Comairco (Ref. 1).

The frequency spectrum is known from the manufacturer, the fan is 6 bladed and of 18" diameter and the rotor is 5 lobed, but geared at 3.7 times motor speed therefore the blade passage frequency (or lobe passage frequency) is

$$\text{RPM} \times \frac{1}{60} \times \text{No. of Blades} = \frac{1775}{60} \times 6 = 177.5 \text{ Hz}$$

$$\text{and RPM} \times \frac{1}{60} \times \text{No. of Lobes} = \frac{1775}{60} \times 5 \times 3.7 = 547.3 \text{ Hz}$$

From Ref. 2 a sound pressure level spectrum is available. If we make the reasonable assumption that the noise emanating from the machine is equally split between rotor and fan (ie. 80 dBA each) we can divide the sound pressure into a spectrum using the information in Ref. 2 as shown in Table 1. It is further assumed that all noise from fan radiates through the duct and all noise from compressor through the wall.

2.2 TRANSMISSION LOSS FOR WALLS AND ROOF FROM COMPRESSOR

The walls are assumed to be $\frac{1}{2}$ inch fir plywood mounted on 2 inch x 2 inch wood battens at 16 inch centres (Ref. 3). The space between steel outer wall and plywood will be filled with fibreglass. Based on methodology in Chapter 11 of Ref (4).



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Plateau Height For Plywood = 19 dB

Plateau Breadth Ratio = 6.5

Density = 600 kg/m³

Surface Density = 11.25 kg/m²

Surface Density - critical frequency product = 12,700 Hz-Kg/m²

Normal Incidence loss at Critical Frequency f_c = 40 dB

Field Incidence Loss @ 1000 Hz = 37 dB

The resulting transmission loss characteristic for the walls and roof for the plywood alone is shown in Fig. 1. Since the outer wall is floppy and has cracks no credit will be taken for its effect on the noise.

2.3 FAN NOISE REDUCTION BY DUCT

From Ref. 5

Attenuation = $12.6 \frac{P}{A} \cdot a^{1.4}$ per foot

where for $a = 0.8$ for 1" liner

and $P = 19 \times 2 + 22 \times 2 = 82"$

$A = 19 \times 22 = 418"$

Attenuation = $12.6 \times \frac{82}{418} \times 0.8^{1.4} = 1.8$ dB/ft

4 foot duct = 7.2 dB



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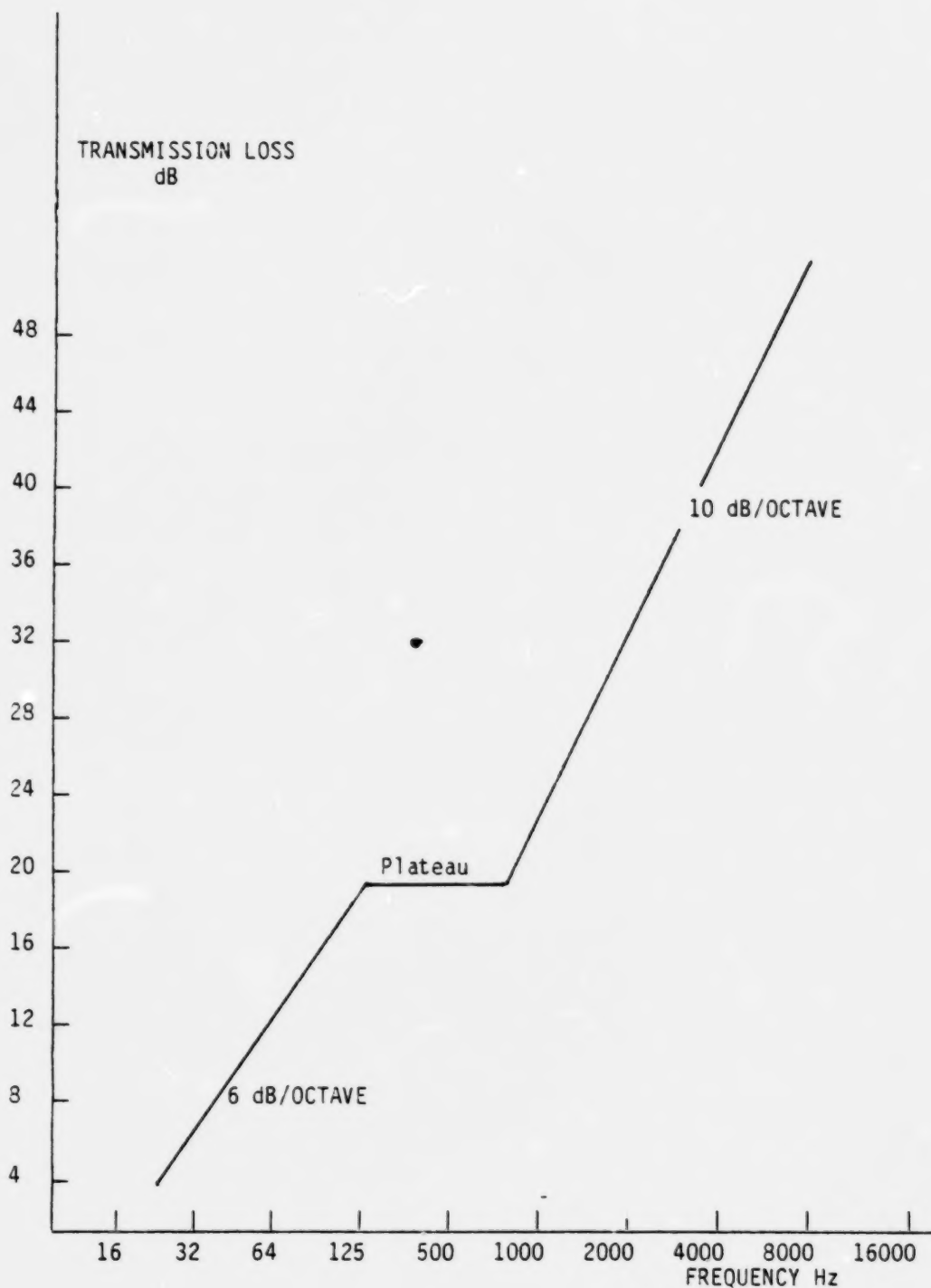


FIGURE 1: TRANSMISSION LOSS FOR PLYWOOD



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FREQUENCY HZ	SOUND PRESSURE LEVEL FROM REF. 2	TRANSMISSION LOSS FROM FIG. 2	RESULTING S.P. LEVEL	
63	72	-13	59	
125	74	-19	53	
250	76	-19	57	
500	80	-19	61	
1000	74	-22	52	
2000	66	-32	34	
4000	62	-42	20	
8000	55	-52	3	
		-	65 dB	

TABLE 1: NOISE REDUCTION BY WALL (COMPRESSOR ONLY)



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INB

To achieve required ^{the}14 dB reduction ^{an}8 foot duct in and out is required, or a proprietary silencer with an attenuation of 14 dB. With ^a90° bend approximately 6 foot ^{of}duct is sufficient, but expense and space limitations prevent this solution unless proven necessary by Test.

2.4 RESULTING NOISE LEVEL AT DISTANCE OF 5 M

Resulting External Noise Level is sum of 65 dB through walls and 78 dB through ducts or 79 dB just outside walls at say 1 m. If inlet and exhaust are towards R&D building we can allow further hemispherical loss to nearest people (say 5 m) which would ideally be 14 dB, however because of wall reflections only 7 dB credit will be assumed. In addition the two sounds should be added in each frequency band and 'A' weighted as shown in Table 2 below, resulting in an overall 68 dBA at 5 m from the shed.

Frequency Band Hz	Compressor Noise Through Walls dB	Fan Noise Through Duct dB	Sum of Sources dB	Sum of Sources dBA	Sum of Sources @ 5 m
63	59	65	67	32	25
125	53	67	67	47	40
250	57	69	70	60	53
500	61	73	74	71	64
1000	52	67	68	68	61
2000	34	59	59	60	53
4000	20	55	55	56	49
8000	3	48	48	48	41
-	66 dB	78 dB	79 dB	75 dBA	68 dBA

TABLE 2: 'A' WEIGHTED SOUND PRESSURE LEVELS

The required geometry is shown in Figures 2 and 3.



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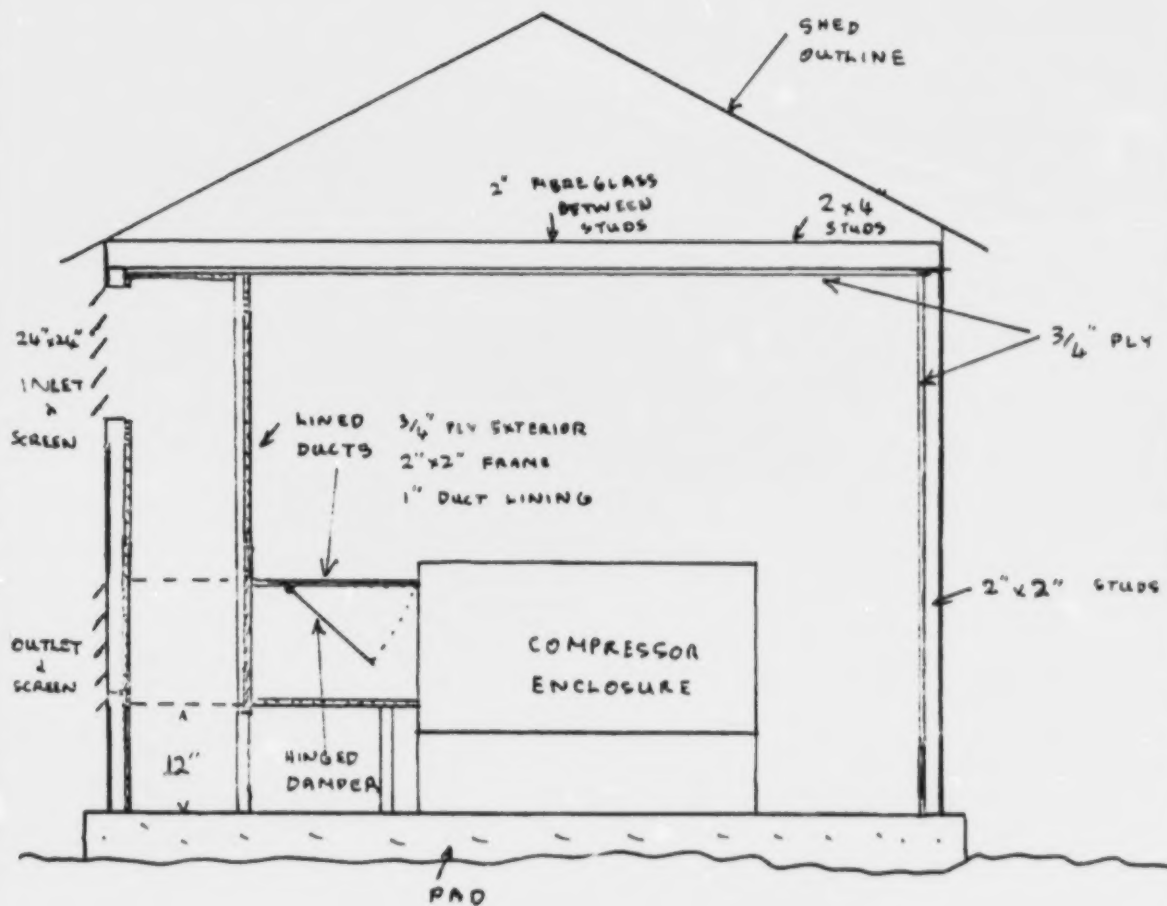


FIGURE 2: REQUIRED INLET AND EXHAUST DUCTS
(ALSO SEE PLAN VIEW - FIGURE 3)



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MVB

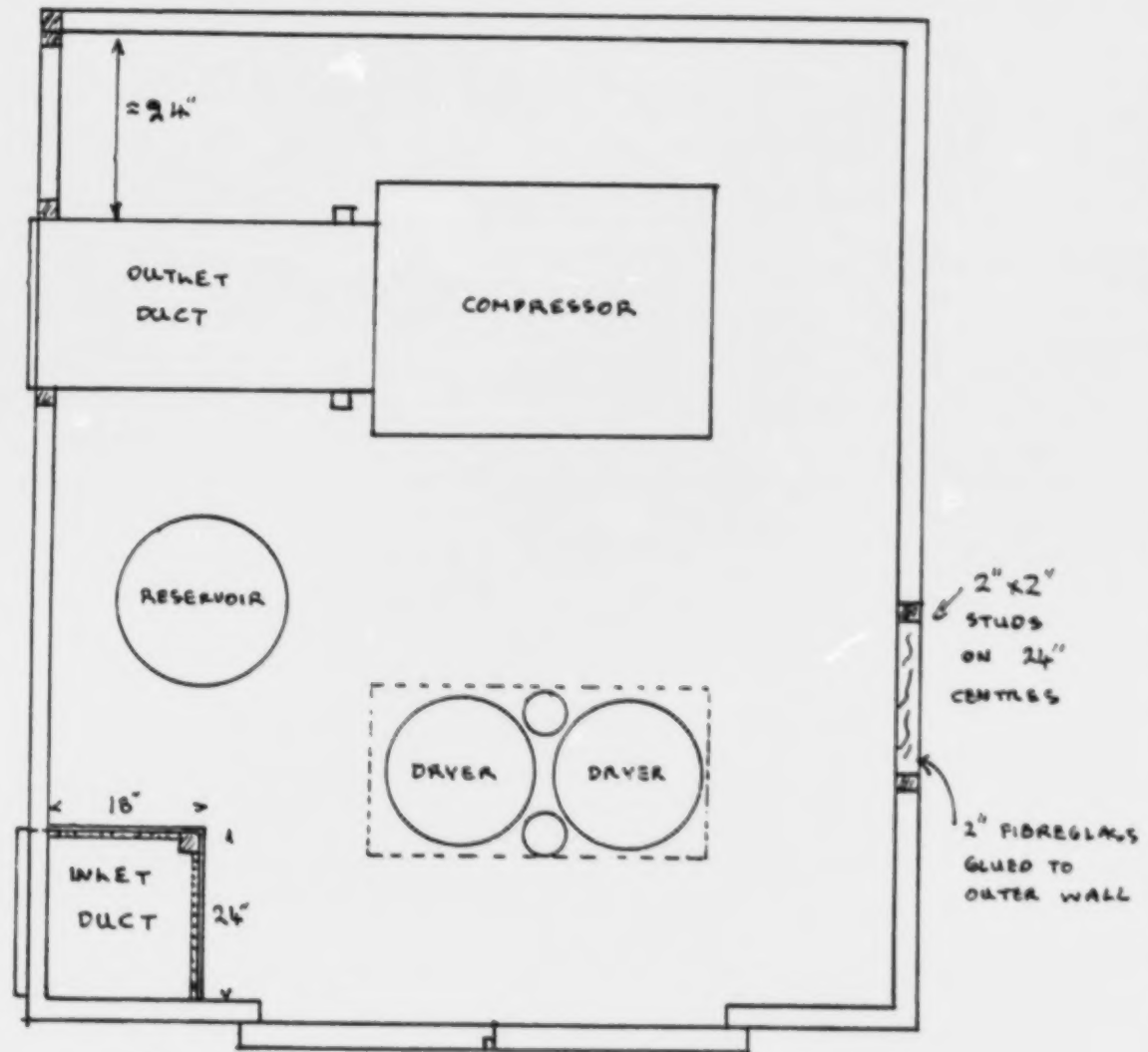


FIGURE 3: REQUIRED INLET AND EXHAUST DUCTS PLAN VIEW



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3.0 CONCLUSIONS & RECOMMENDATIONS

The transmission loss through the walls is sufficient to reduce the raise transmitted by this path to 65 dB. The problem is in the inlet and outlet ducts where 6 feet of lined duct and a 90° bend will be required or a proprietary silencer of 18" square cross section and an attenuation of at least 14 dB. The result would be an external noise 1 m from the shed of 68 dB total.

The preferred solution is to have inlet and outlet on the R&D side (west) of the building, when 68 dBA at 5 m from the east side of the shed will be possible.



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- 3) "Transporter Design Review - Air Supply System" 447-550-002 by K.C.F.
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A7

DEVELOPMENT OF AN
AIR BEARING TRANSPORTATION SYSTEM
MILESTONE NO. 3 REPORT

SUBMITTED TO: TRANSPORTATION DEVELOPMENT CENTRE
CONTRACT SERIAL NO: OSD83-00047



UTDC RESEARCH & DEVELOPMENT LTD.
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MILESTONE NO. 3 SUMMARY
DEMONSTRATION TRACK
CONSTRUCTION AND COMMISSIONING

Report No.: 447-900-032

Date: 84.07.16

D.S.S. Contract Serial No. OSD83-00047

Prepared By JS

Approved By S. J. J. J.
Project Manager



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MILESTONE REPORT #3

SUMMARY

The construction of the demonstration track began 28 December 1983 and all equipment was installed by 29 June 1984. The commissioning tests occupied the month of July, although some specific tests such as track friction levels will be carried out after a period of demonstration running in order to stabilize friction levels after shoe/rail polishing. These tests will be fully reported to TDC at a later date.



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5.2	"Commissioning Test Plan" 447-610-001	
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5.4	"Preliminary Friction Tests" 447-610-002	
5.5	"Integrated System Tests" 447-610-005	
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1.0

PURPOSE

To report on the construction and commissioning of the demonstration test track, particularly the following features which were being installed for the first time (Ref. 1):

- o Purpose designed reinforced concrete guideway slab with provision for flush installation of all rail, LIM's, sensors and connections, fasteners, etc.
- o Rail expansion joint.
- o Freezing protection for air supply and rail surface.
- o LIM surface protection.
- o Control of LIM thrust level and on-off functions.
- o Emergency stop systems for entire track and station overrun.
- o Curving sections of 70 m radius using elastically deformed rail.
- o Simple pedestrian crossing warning system.
- o Acoustically treated compressor.

It is not the intention of the Milestone Summary Report to report routine construction work or tests, but to focus on unique features of the system and lessons learned.



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2.0 REVIEW OF WORK CARRIED OUT

2.1 CIVIL WORKS

The civil works included all excavation, backfilling, form work, concrete pouring, finishing and erection of compressor hut on a concrete pad. The late start of the program in extremely cold (-25°C) weather and deep frost penetration, made progress slow, and increased costs. This was a result of longer contractor time on site and the necessity for a large heated tent for protection of the newly poured concrete.

Problem areas that have shown up later in the program are:

- o Poor concrete properties near the surface, evidence of some freezing during the cure period.
- o Uneven surface of rail slot necessitating time consuming repairs and shimming.
- o Insufficient clearances around LIM and sensors, unnecessarily increasing installation time.

The other features of this work are reported in more detail in Attachment 5.1.

2.2 RAIL INSTALLATION

Rail installation to an approximately 70 m curve proved relatively easy. The problems were concentrated at the joints, especially track joints at which some thermal expansion had to be allowed. This usually was a result of



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poor welding on the rail clips and rail plugs. Clearly, quality control must be improved in a production installation. An attempt to use non-skilled labour proved time consuming and exaggerated the problems.

2.3 AIR SUPPLY

The objectives of providing a clear, dry, heated, and quiet air supply were met in all respects by the design described in the Milestone No. 2 Report. Noise measurements are reported here in Attachment 5.3. Initial compressor operation was achieved during freezing weather, and no problems of system icing occurred. A brief test of the heater system showed that it did function, but the extent must be determined in the forthcoming winter.

2.4 ELECTRICAL SYSTEM

Installation and testing of the electrical system proceeded largely without a hitch and a local electrical contractor carried out the work efficiently and on budget. The sole exception was the problem discovered with failed LIM insulation reported in Attachment 5.6. In brief, the insulation of the LIM's fell to unacceptably low levels, especially after rain. Eight (8) of twenty-one (21) LIM's were rewound and are currently acceptable. The performance of the insulation will be monitored during demonstration.

2.5 CONTROL SYSTEM

Two features of the control system proved to consume much time and effort during installation and commissioning.



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- o The proximity sensors used have limited sensing range and need adjustment very close to the vehicle. This occasionally results in mechanical interference.
- o The memory of the Texas Instruments PLC chosen was too small, resulting in very time consuming program manipulation to achieve simple changes. This was not a problem inherent in the PLC, merely the particular model chosen.

2.6

COMMISSIONING

The commissioning Test Plan is described in detail in Attachment 5.2. In general, the individual system tests were routine and such tests as wiring continuity and wiring coding, are not reported unless a specific anomaly with relevance to Transporter design and construction was noted.

During integrated testing, speeds up to 3.0 m/s were achieved at low vehicle weights and the design speed of 1.0 m/s achieved at all required test weights. The vehicle acceleration and braking system, including emergency stop, met all requirements. The major problem areas were:

- o Eliminating mechanical interference between vehicle and track at all weights.
- o Obtaining consistent stopping positions that would allow automatic system restart.



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The small air-gaps required are discussed in Ref. (2) and are a direct result of LIM design for 60 Hz. An increase in allowable air-gap would greatly simplify vehicle and track design. Friction levels in the curves are acceptable and are reported in Attachments 5.4 and 5.7.



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Bearing Transportation System

By

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CONCLUSIONS AND RECOMMENDATIONS

The following conclusions have been drawn from the work carried out:

- o In order to reduce costs and later installation problems, cold weather construction should be avoided.
- o A simpler track bed would have speeded later tests.
- o A LIM design suited to Transporter with larger airgap would simplify vehicle, track and development problems.
- o Air supply systems have been resolved, subject to a definitive heater test.
- o A rail joint design has been developed which, although serviceable, requires improvement.
- o Vehicle performance is smooth and jerk free and meets all requirements.



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REFERENCES

- 1) "Work Planning" 447-900-009 by JHS.
- 2) "Vehicle Suspension and Structural Deflections"
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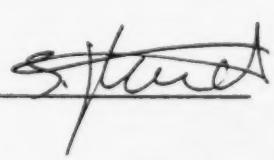
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TEST PLAN

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Date: 84 05 22

Prepared By: T.W

Approved By: 



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SUMMARY

A 40 meter Transporter System has been installed at the TDC Millhaven. The System embodies all the power and control elements likely to be found in any such system regardless of size. Commissioning tests for the System are described.



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1.0

BACKGROUND

The complete Transporter System has been installed, namely: track slab, running rails, LIM primaries, vehicle position sensors, air compressor, air heater, air distribution system, air valves, contactors, all wiring, programmable logic control unit, track safety stops, audible warning system, user controls, pedestrian controls, pedestrian signs and visual warnings, pedestrian barriers, engineering test vehicle (ETV) and the "DISNEY" vehicle body.

Some components and subsystems have been in service previously, some have not.

It is necessary to check every aspect of the system in an orderly, thorough manner in order to establish serviceability and performance at the commencement of service; and by this means obtain a reference datum against which future performance levels can be compared. In addition, engineering design activities require data for more thorough understanding and the ability to predict behaviour. It is with this background that a Commissioning Test Plan is developed to satisfy these requirements.



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2.0

PURPOSE

The Commissioning Test Plan has the following objectives:

- o Minimize risk of injury to personnel during commissioning;
- o Minimize risk of damage to system components during commissioning;
- o Optimize utilization of manpower, time, materials and equipment during commissioning;
- o Provide the necessary contribution to the program engineering data base;
- o Provide commissioning activity documentation;
- o Commission the Transporter System.

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3.0 EXAMINATION OF APPROACHES

3.1 SITE, SLABS AND TERMINUS

(Refer to references 2,3,4, & 5)

By inspection and measurement it will be verified that the location, dimensions and method of construction of the test article comply with the referenced drawings. Deviations will be noted on the test card (to be developed) for review leading to test article rework and/or drawing revision.

3.2 TRACK

(Refer to references 6,7 & 8)

Note: Reference 8 is used to establish track gauge (i.e. 1000 mm between rail centres) pending program documentation revision for satisfactory definition.

By inspection and measurement it will be verified that the location, dimensions and method of construction of the test article comply with the referenced drawings. Deviations will be noted on the test card (to be developed) for review leading to test article rework and/or drawing revision.

(This activity checks LIM primaries, sensors and divers track-related components for location and orientation.)

3.2.1 Individual Running Rails

(Refer to references 9 & TBD)

The rails will be inspected with respect to surface finish, hole pattern and joint condition. Rail alignment will be checked. Coordinates of rail joints and rail curvature will be measured. Each rail will be cleaned.



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Definitive specifications for the running rail cross-section and air-hole pattern are not available within program documentation at time of writing. Therefore a 'known good' specimen of rail cross-section will be used to master a template which, in turn, will be used to check the entire length of each running rail for distortion. Air-hole pattern will be compared with reference T80.

3.2.2 Running Rails (As a Pair)

(Refer to reference 8)

Note: Reference 8 is used to establish track gauge (i.e, 1000 mm between rail centres) pending program documentation revision for satisfactory definition.

Gauge and relative angle of running rails will be checked using a tool fabricated for the purpose.

3.3 WIRING

3.3.1 Power Wiring

(Refer to references 10,11,12 & 39)

As part of the compressor installation work, the subcontractor demonstrated design compliance. Further, because the compressor has been used since installation in the present location, power wiring to this component is deemed satisfactory and is not subject to further tests or inspection in this Plan.

All other power wiring will be checked for continuity, insulation and identity marking before the application of power. Necessary circuit isolation by breaking fixed connections will be minimized by fuse removal, manual operation of contactor and/or test method.



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3.3.2 Control Wiring

(Refer to references 13,14 & 39)

All control wire identities will be checked before application of power. Where practical, wires will be checked for continuity and insulation resistance. Specific steps necessary to complete this activity are detailed as appropriate in Section 5.0.

3.4 SENSORS

(Refer to reference 15)

Position sensors will have been characterized before installation. Function will be verified manually by introduction of a suitable hand-held object while observing the logic control unit monitor.

Pressure sensitive switches will be checked in-situ by application and removal of pressure while observing the logic control unit monitor.

3.5 AIR SYSTEM

3.5.1 Compressor

The compressor installation will be checked visually against a checklist, start-up performance will be measured, duty-cycle in prescribed Transporter System operating modes will be measured, reservoir decay capacity will be measured, shut-down procedure will be verified, emergency procedures will be verified and prescribed failure modes will be investigated.

Temperature rise within the compressor hut, at prescribed flap settings, will be measured.



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Reference 16 reports that the steps taken to reduce compressor hut noise emission meet or exceed design objectives. UTDC Facilities Dept. (E. Elsliger) has expressed complete satisfaction with the low noise levels achieved. This aspect of the system, therefore, is not subject to further activity in this plan.

3.5.2 Distribution and Control

(Refer to references 9,15,17,18,19 & 20)

The air distribution system will be checked for leaks and correct assembly.

Location and operation of hand valves will be checked.

Pressure rise after switch-on will be measured and recorded for each track section.

3.6 VEHICLES

3.6.1 General

The following paragraphs, 3.6.2 through 3.6.6, will be carried out for ETV #2. Further activity TBD.

3.6.2 Base

(Refer to references 21, 22 & 23)

Note: Reference 23 is used to define reaction rail (LIM secondary) mounting modifications.

By inspection and measurement it will be verified that the location, dimensions; method of attachment and method of



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construction of the test article comply with the referenced drawings. Deviations will be noted on the test card (see appendix) for review leading to test article rework and/or drawing revision.

3.6.3 Shoes and Suspension

(Refer to references 23,24,25,26,27, & 31)

Note: Reference 23 is to be used to provide necessary background.

By inspection and measurement it will be verified that the location, dimensions, method of attachment and method of construction of the test article comply with the reference drawings. Deviations will be noted on the test card (see appendix) for review leading to test article rework and/or drawing revision.

3.6.4 LIM Secondary (Reaction Rail)

(Refer to reference 23,28,29 & 30)

Note: Reference 23 is to be used to provide necessary background.

By inspection and measurement it will be verified that the location, dimensions, method of attachment and method of construction of the test article comply with the reference drawings. Deviations will be noted on the test card (see appendix) for review leading to test article rework and/or drawing revision.



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3.6.5 Sensor Rail

(Refer to references 32 & 33)

Note: Reference 23 is to be used to provide necessary background.

By inspection and measurement it will be verified that the location, dimensions, method of attachment and method of construction of the test article comply with the reference drawings. Deviations will be noted on the test card (see appendix) for review leading to test article rework and/or drawing revision.

3.6.6 Vehicle Link

(Refer to reference 34)

The vehicle link will not be commissioned in this plan.

3.6.7 Integrated Vehicle

Vertical deflection of shoes and structure for prescribed loads up to and including full rated load will be measured and noted on the test card.

3.7 FRICTION

(Refer to reference 38)

Friction between 'signed-off' rail and 'signed-off' vehicle will be measured in both directions for prescribed gross vehicle weights with rail air at prescribed pressure. LIMs will not be energized. Sensor status will be immaterial. Tractive effort will be applied at the reaction rail as closely as practical along the reaction rail long axis. The force will be applied via a load cell, the conditioned output from which will be continuously recorded. If practical, speed



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will be continuously recorded on the same record. Direction and location also will be noted on the record. Motive power for this test will be provided by one or more pedestrians operating in the 'pull' mode. The effect of the natural irregularities in tractive effort produced by this method will be minimized by the use of a suitably ballasted vehicle between the puller(s) and the test article.

3.8 CONTROL SYSTEM

3.8.1 User Controls

(Refer to references 35 & 36)

Note: Reference 37 may be used to provide useful background.

With LIM primaries inert and all other systems and auxiliaries operating, the Transporter will be exercised by means of the user controls, in each user and emergency mode. The test vehicle will be moved manually as prescribed in Section 8.0 (Test Plan). Correct operation of contactors, sensors, solenoid valves and frequency inverter will be ascertained.

3.8.2 Non-User Controls

(Refer to references 35 & 36)

Note: Reference 37 may be used to provide useful background.

With LIM primaries inert and all other systems and auxiliaries operating, the Transporter will be exercised by means of the non-user controls, in each user and emergency mode. The test vehicle will be moved manually. Correct operation of contactors, sensors, solenoid valves and frequency inverter will be ascertained.



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3.9 HEATER

(Refer to references 40 & 41)

Heater cycle time will be recorded. Three-phase current and applied 3-phase voltage will be measured.

Due to unfavourably mild ambient conditions expected to prevail throughout the commissioning period, the temperature rise of compressed air flowing through the heater and the temperature distribution in the track will not be measured at this time.

3.10 FREQUENCY INVERTER

Frequency inverter operation in each design mode will be verified. The equipment will be operated with output un-loaded, in the first instance, as part of 3.8 and finally, fully operational, as part of 3.12. Three-phase input voltage and current, three-phase output voltage, current and frequency will be measured for prescribed modes. Emergency procedures will be verified.

3.11 LOGIC CONTROL UNIT

This subsystem, including software, will have been partially tested separately as part of the software development prior to installation. Further verification will be afforded by the Control System Test 3.8. Finally, fully satisfactory operation will be demonstrated by the Integrated Transporter System Test 3.12.

Throughout the referenced tests the Logic Control Unit will be operated in conjunction with Logic Control Unit Monitor and Printer. Together, these peripherals will provide valuable trouble-shooting and engineering information while the hard copy will assist documentation and reporting.



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3.12 LIM's

The LIM's will be checked individually for correct thrust direction (i.e., correct phase rotation). This will be accomplished by manually programming the programmable logic controller from the keyboard, holding an aluminum shovel above the LIM selected and observing thrust direction. Any necessary corrective action will be taken.

3.13 INTEGRATED TRANSPORTER SYSTEM

Following check and test of all subsystems as detailed in this plan the integrated system will be tested. The system will be operated in each mode. Vehicle performance will be measured and continued satisfactory operation of subsystems will be verified. The integrated Transporter System will be commissioned.



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4.0 TEST VARIABLES

4.1 SITE, SLABS AND TERMINUS (Drawing List)

Note: The list of variables following is not exclusive. Any and all observed deviations of the test article from the referenced drawings will be noted.

The location, dimensions and method of construction of:

- o Concrete track slab
- o Concrete compressor slab
- o Air supply installation from compressor to mechanical equipment room
- o Air supply installation from compressor to track
- o Main cross trench
- o Curves #1 and #2
- o Expansion joints
- o Track slab cross-section
- o Conduits (for wire and cable)

4.2 TRACK (Drawing List)

Note: The list of variables following is not exclusive. Any and all observed deviations of the test article from the referenced drawings will be noted.

The location, orientation and method of attachment of:

- o LIM Primaries
- o Position switches
- o Rails
- o User controls
- o Building mounted visible and audible warnings



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4.2.1 Individual Running Rails

- o Surface finish
- o Air-hole pattern
- o Joint condition
- o Rail alignment
- o Joint coordinates
- o Rail curvature coordinates
- o Rail cross-section
- o Rail (running surface) cleanliness

4.2.2 Running Rails (As a Pair)

- o Rail gauge
- o Relative angle of adjacent rail cross-section

4.3 WIRING

4.3.1 Power Wiring

(Drawing List)

Note: The list of variables following is not exclusive. Any and all observed deviations of the test article from the referenced drawings will be noted.

- o Conductor continuity
- o Insulation resistance
- o Wire identity marking
- o Termination style and execution



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4.3.2 Control Wiring

(Drawing List)

Note: The list of variables following is not exclusive. Any and all observed deviations of the test article from the referenced drawings will be noted.

- o Conductor continuity
- o Insulation resistance
- o Wire identity marking
- o Termination style and execution

4.4 SENSORS

4.4.1 Input Variables

- o Proximity, to each position sensor, of metallic mass
- o Pressure of air to which pressure switch(es) are exposed

4.4.2 Output Variables

- o Logic control unit status

4.5 AIR SYSTEM

4.5.1 Compressor

4.5.1.1 Input Variables

- o Transporter system operating mode
- o Compressor mode
- o Compressor hut flap settings
- o Ambient temperature
- o Relative Humidity
- o Hut insolation



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4.5.1.2 Output Variables

- o Compressor running time
- o Compressor duty cycle
- o Compressor status
- o Temperature in compressor hut
- o Reservoir pressure
- o Reservoir pressure decay time

4.5.2 Distribution and Control

4.5.2.1 Input Variable

- o System air pressure (for each track section where applicable)
- o Hand valve status
- o "Time of Switch-on" (for each track section)

4.5.2.2 Output Variables

- o Loss of air from joints and/or system components
- o Effect of hand valves
- o Time history of pressure rise, in each track section, following "switch-on"

4.6 VEHICLES

4.6.1 General

This sub-section applies to ETV#2. Further activity TBD.



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4.6.2 Base

(Drawing List)

The dimensions and methods of construction of:

- o Main frame
- o Upper frame
- o Cross members
- o P/U blocks

4.6.3 Shoes & Suspension

(Drawing List)

The dimensions, methods of construction and methods of attachment of:

- o Shoe P/U
- o Shoe carrier adapters
- o Shoe assemblies
- o Adapter plates

4.6.4 LIM Secondary (Reaction Rail)

(Drawing List)

The dimensions, methods of construction and methods of attachment of:

- o Back iron
- o Reaction rail cap
- o Reaction rail stiffeners



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4.6.5 Sensor Rail

(Drawing List)

The dimensions, methods of construction and method of attachment of:

- o Sensor rail

4.6.6 Vehicle Link

Not applicable

4.6.7 Integrated Vehicle

(Drawing List)

4.6.7.1 Input Variables

- o Rail curvature
- o Rail profile
- o Moisture content of shoe filler
- o Ambient conditions:
 - i) Wind speed & direction
 - ii) Temperature
 - iii) Relative humidity
- o Vehicle weight
- o Vehicle load
- o Time
- o Shoe/rail alignment
- o Shoes & suspension (refer to 4.6.3)

4.6.7.2 Output Variables

- o Vertical deflection of structure
- o Vertical deflection of shoes
- o Vertical deflection of LIM secondary



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4.7 FRICTION

(Drawing List)

4.7.1 Input Variables

- o Tractive effort
- o Rails (Refer to 4.2.1 & 4.2.2)
- o Rail (air) temperature
- o Rail air pressure
- o Vehicle weight
- o Vehicle load
- o Gradient
- o Direction of travel
- o Alignment of tractive effort (angle with and displacement from test article reaction rail longitudinal axis)
- o Shoes and suspension (Refer to 4.6.3)
- o Ambient conditions
 - i) wind (speed & direction)
 - ii) temperature
 - iii) relative humidity

4.7.2 Output Variables

- o The speed of the vehicle
- o The acceleration of the vehicle

4.8 CONTROL SYSTEM

(Drawing List)



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4.8.1 User Controls

4.8.1.1 Input Variables

- o Vehicle position (sensor rail position)
- o Vehicle speed (sensor rail speed)
- o Direction of vehicle travel (sensor rail direction)
- o "Start/Call" push button operation at
 - i) East Station
 - ii) West Station
- o "Stop" push button operation at
 - i) East Station
 - ii) West Station
- o "Emergency" push button operation at
 - i) East Station
 - ii) West Station

4.8.1.2 Output Variables

- o Position Sensor system status
- o LIM power distribution (contactor) system status
- o Frequency inverter status
- o Air distribution system solenoid valve status
- o "System Ready" light status at
 - i) East Station
 - ii) West Station
- o Visible warning operation
- o Audible warning operation
- o Time interval:
 - i) "Start/Call" until vehicle movement
 - ii) Vehicle captive at station(s)
- o Frequency inverter:
 - i) Output frequency
 - ii) Output voltage



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4.8.2 Non-User Controls

4.8.2.1 Input Variables

- o Control panel control status
- o Vehicle position (sensor rail position)
- o Vehicle speed (sensor rail speed)
- o Direction of vehicle travel (sensor rail direction)
- o "Emergency" push button operation at
 - i) East Station
 - ii) West Station

4.8.2.2 Output Variables

- o Position Sensor system status
- o LIM power distribution (contactor) system status
- o Frequency inverter status
- o Air distribution system solenoid valve status
- o "System Ready" light status at
 - i) East Station
 - ii) West Station
- o Visible warning operation
- o Audible warning operation
- o Time interval:
 - i) Vehicle waiting time
 - ii) Additional waiting time
- o Frequency inverter:
 - i) Output frequency
 - ii) Output voltage

4.9 HEATER

(Drawing List)



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4.9.1 Input Variables

- o 3-phase current
- o 3-phase voltage

4.9.2 Output Variables

- o "On" time
- o "Off" time

4.10 FREQUENCY INVERTER

(Drawing List)

4.10.1 Input Variables

- o Input current (3-phase)
- o Input voltage (3-phase)
- o Command signal input

4.10.2 Output Variables

- o Power consumption
- o Output frequency
- o Output voltage (3-phase)
- o Output current (3-phase)

4.11 LOGIC CONTROL UNIT

4.11.1 Input Variables

- o Binary status of each of two air pressure sensitive switches.
- o Binary status of each of twenty one proximity sensors (vehicle position sensors).
- o Logic Control Unit program

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4.11.2

Output Variables

- o Status of 4-bit digital output (PLC08-5 thru -8).
- o Binary status of each of three output lines (PLC08-2, -3 & -4).
- o Accuracy and utility of hard copy printed output
- o Accuracy and utility of monitor display.

4.12

LIM's

4.12.1

Input Variables

- o Programmable logic controller status

4.12.2

Output Variables

- o Direction of LIM thrust

4.13

INTEGRATED TRANSPORTER SYSTEM

4.13.1

Input Variables

- o Vehicle load
- o System supply voltage(s)
- o Operating mode
- o Operator demand
- o Ambient conditions:
 - i) wind speed/direction
 - ii) temperature
 - iii) relative humidity



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4.13.2 Output Variables

- o Vehicle performance:
 - i) acceleration rate
 - ii) brake rate
 - iii) cruise speed
 - iv) stopping distance
 - v) jerk/snatch
 - vi) ride comfort
 - vii) journey time
- o LIM performance:
 - i) temperature of primary
 - ii) temperature rise of secondary cap
 - iii) gap
 - iv) thrust
- o Frequency inverter performance (refer to 4.10)



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5.0 MEASUREMENT OF TEST VARIABLES

5.1 SITE, SLABS AND TERMINUS

Identified variables will be measured using measuring tape, plumb line, level gauge, calipers, rule and straightedge etc. as required.

5.2 TRACK

Identified variables will be measured using measuring tape, plumb line, level gauge, calipers, rule and straightedge etc. as required.

5.2.1 Individual Running Rails

Identified variables will be measured using measuring tape, plumb line, level gauge, calipers, rule and straightedge etc. as required.

In addition, a special tool will be used to check rail cross-section.

5.2.2 Running Rails (As A Pair)

The special gauge manufactured for installation will be used.

5.3 WIRING

5.3.1 Power Wiring

- o Continuity will be checked using an ohmmeter. Wires and/or circuits tested will be isolated and/or configured as required.



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- o Insulation will be checked using a 500 Vac insulation measurement instrument. Wires and/or circuits tested will be isolated and/or configured as required.
- o Wire identity marking, termination style and execution will be checked visually.

5.3.2 Control Wiring

- o Continuity will be checked using an ohmmeter. Wires and/or circuits tested will be isolated and/or configured as required.
- o Insulation will be checked using a 500 VAC insulation measurement instrument. Wires and/or circuits tested will be isolated and/or configured as required.
- o Wire identity marking, termination style and execution will be checked visually.

5.4 SENSORS

5.4.1 Input Variables

- o Proximity will be reduced to zero by bringing a metallic mass into contact with the sensitive surface of test article.
- o Air pressure in the pipe or manifold adjacent to the test article will be measured using a pressure gauge.



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5.4.2 Output Variables

Logic Control unit status will be measured using the video programming unit (VPU 500).

5.5 AIR SYSTEM

5.5.1 Compressor

5.5.1.1 Input Variables

- o System operating mode will be in full automatic operation.
- o Compressor operating mode is described in Reference 43. The fitted pressure sensor will be monitored and continuously recorded using a chart recorder.
- o Compressor hut flap settings will be varied throughout the range.
- o Ambient temperature and relative humidity will be measured approximately 10 m south of the compressor hut using a sling psychrometer.
- o Insolation will be estimated based on date, time of day and cloud cover, which will be noted.

5.5.1.2 Output Variables

- o Temperature in compressor hut will be measured using a multichannel digital readout thermometer in conjunction with thermocouples.
- o All other output variables will, if practical be continuously recorded on chart recorder in conjunction



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with appropriate transducers. A much less desirable method is to monitor the variables visually by means of existing gauges etc. in conjunction with a stopwatch.

5.5.2 Distribution and Control

5.5.2.1 Input Variables

- o System air pressure (for each track section where applicable) will be continuously monitored by means of a chart recorder in conjunction with suitable transducers.
- o Hand valve status will be checked manually and noted.
- o "Time of Switch-on" (for each track section) will be recorded by means of a chart recorder in conjunction with suitable transducers (TBD but probably 100 kohm: 5 kohm potential dividers).

5.5.2.2 Output Variables

- o Air leaks will be sought using soapy water.
- o Effect of hand valves will be measured by method TBD.
- o Time history of pressure, in each section, will be obtained using chart recorder in conjunction with suitable transducers.

5.6 VEHICLES

5.6.1 Dimensions, etc..

The variables identified in 4.6.2 through 4.6.5 will be measured using measuring tape, calipers, rule, straightedge, etc. as required.



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5.6.2 Integrated Vehicle

5.6.2.1 Input Variables

Note: satisfactory control of rail related variables (curvature and profile) will be facilitated by prior completion of Section 5.2.

- o Rail curvature will be measured per 5.2. A "straight" section will be used.
- o Rail profile will be measured per 5.2.
- o Shoe filler will be "dry". Moisture content will be judged.
- o Ambient Conditions
 - i) Ambient temperature, wind speed and direction will be obtained from TMF Tower Operator
 - ii) Relative humidity will be measured using a sling psychrometer.
- o The vehicle will be weighed by means of a load beam secured to the structure covering the adjacent walkway.
- o Vehicle load will be achieved by means of individually weighed and marked weights.
- o Time will be measured by means of a manually controlled stopwatch.
- o Shoe/rail alignment will be manually adjusted and visually monitored.
- o Shoes and suspension will be observed and noted (refer to 4.6.3).



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5.6.2.2 Output Variables

- o Vertical deflections will be measured using dial indicators.

5.7 FRICTION

5.7.1 Input Variables

- o Rails and gradient are measured in Section 5.2.
- o Rail (air) temperature will be measured by method TBD.
- o Rail air pressure will be measured using hand held pressure gauge.
- o Vehicle weight and load will be measured as in Section 5.6.2.1.
- o Direction of travel will be observed and noted.
- o Alignment of tractive effort will be achieved as described in Section 3.7. Error is considered negligible and will be ignored.
- o Tractive effort will be measured using a load beam the conditioned output from which will be continuously recorded.
- o Shoes and suspension will be observed and noted (refer to Section 4.6.3).
- o Ambient conditions will be measured as in Section 5.6.2.1.



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5.7.2 Output Variables

- o Speed will be measured using a wheel driven DC tachometer the conditioned output from which will be continuously recorded.
- o Acceleration will be reduced from the continuous record of speed referred to above.

5.8 CONTROL SYSTEM

5.8.1 User Controls

5.8.1.1 Input Variables

- o With the exception of vehicle speed all input variables will be physically observed and noted.
- o Vehicle speed will be measured as in section 5.7.2.

5.8.1.2 Output Variables

- o LIM power distribution (contactor) system status, "System Ready" light status, visible warning operation; audible warning operation and frequency inverter status will be physically observed and noted.
- o Position sensor system status, air distribution system solenoid valve status will be monitored using the video programming unit (VPU 500).
- o Time intervals will be measured by means of a hand operated stopwatch.
- o Frequency inverter output frequency will be measured by means of an electronic digital frequency counter. The



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input to the counter will be a low level square wave derived internally within the inverter. The frequency of the square wave is 3360 times output frequency.

- o Frequency inverter output voltage will be monitored using an oscilloscope and measured using a digital voltmeter.

5.8.2 Non-User Controls

5.8.2.1 Input Variables

- o With the exception of vehicle speed all input variables will be physically observed and noted.
- o Vehicle speed will be measured as in section 5.7.2.

5.8.2.2 Output Variables

- o LIM power distribution (contactor) system status, "System Ready" light status, visible warning operation; audible warning operation and frequency inverter status will be physically observed and noted.
- o Position sensor system status, air distribution system solenoid valve status will be monitored using the video programming unit (VPU 500).
- o Time intervals will be measured by means of a hand operated stopwatch.
- o Frequency inverter output frequency will be measured by means of an electronic digital frequency counter. The input to the counter will be a low level square wave derived internally within the inverter. The frequency of the square wave is 3360 times output frequency.



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- o Frequency inverter output voltage will be monitored using an oscilloscope and measured using a digital voltmeter.

5.9 HEATER

5.9.1 Input Variables

- o Three-phase voltage will be measured using a digital voltmeter connected between phases in turn, at the contactor in the Control panel.
- o Three-phase current will be measured using a clamp-on current probe in conjunction with an analog instrument, for each phase in turn. The measurement will be made adjacent to the contactor in the Control panel.

5.9.2 Output Variables

The identified output variables will be measured by continuously recording the output of a current probe encircling one of the heater wires.

5.10 FREQUENCY INVERTER

5.10.1 Input Variables

- o Three-phase voltage will be measured using a digital voltmeter connected between phases in turn. This will be done either at the main fused disconnect with the door open or within the frequency inverter.



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- o Three-phase current will be measured using a clamp-on current probe in conjunction with an analog instrument, for each phase in turn. This will be done either at the main fused disconnect with the door open or within the frequency inverter.

5.11 LOGIC CONTROL UNIT

5.11.1 Input Variables

- o Binary status of air pressure sensitive switches will be ascertained by use of a voltmeter or a oscilloscope to measure the voltage across the switches at the input to the LCU.
- o Binary status of proximity sensors will not be ascertained, unless unforeseen difficulty develops, other than by, measuring the associated output variable (4.11.2 entry four).
- o A printed copy of the PLU program is included as an appendix to Ref. 42.

5.11.2 Output Variables

- o 4-bit digital output will be monitored using an oscilloscope at PLC08-5 through -8.
- o Status of three output lines will be monitored using an oscilloscope at PLC08-2, -3 & -4.



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- o Hard copy printout will be assessed by cognizant engineer.
- o Monitor display will be assessed by cognizant engineer.

5.12 LIM's

5.12.1 Input Variables

- o The PLC will be manually programmed from the keyboard.

5.12.2 Output Variables

- o By observing direction of movement of aluminum shovel.

5.13 INTEGRATED TRANSPORTER SYSTEM

5.13.1 Input Variables

- o Vehicle load will be measured as in Section 5.6.2.1.
- o Supply voltage will not be measured.
- o Each operating mode will be noted, in turn.
- o Ambient conditions will be obtained from TMF tower operator and will be noted.

5.13.2 Output Variables

- o Vehicle performance:
 - 1) Jerk, snatch and ride comfort will be judged by cognizant personnel of known body weight.



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- 2) Other variables will be reduced from a continuous record of vehicle speed obtained by recording the conditioned output from a wheel driven tachometer. The wheel will be towed by the Transporter vehicle.



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6.0

TEST CARDS

Test cards will be developed as part of each test.
Appropriate specific procedures and test cards developed in
previous Transporter programs may be used (44).

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- 2: Dwg. No. 68-401-020, Rev. 0. "Transporter Track Site".
- 3: Dwg. No. 68-401-021, Rev. 0. "Transporter Slab Details".
- 4: Dwg. No. 68-401-022, Rev. 0. "Transporter Slab Sections".
- 5: Dwg. No. 68-401-023, Rev. 0. "Transporter Terminus Details".
- 6: Dwg. No. 68-201-010, Rev. 0. "Transporter Equipment (Track) Orientation".
- 7: Dwg. No. 068-401-025, Rev. 0. "Rail to Base Securing".
- 8: Report No. 447-510-003, Issue 1, 83-12-22, "Transporter Track Development Vehicle Interface", by K.C. Falconer.
- 9: Dwg. No. 068-401-024, Rev. 0. "All Weather Operation Gas Tight Rail Slip Joint".
- 10: Dwg. No. 68-201-005, Rev. 0. "Transporter Power Supply".
- 11: Dwg. No. 68-201-007, Rev. 0. "Transporter Outside Power Wiring".
- 12: Dwg. No. 68-201-008, Rev. 0. Two Door Panel Box 1829 X 1524X254(72"X60"X10") c/w 305H(12")feet. "Contactor Box for Transporter".



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- 13: Dwg. No. 68-201-006, Rev. 0. "Transporter Outdoor Control Wiring".
- 14: Dwg. No. 68-201-012, Rev. 0. "Control Enclosure Layout".
- 15: Dwg. No. 068-401-019, Rev. 0. "Pneumatic Diagram".
- 16: Report No. 447-550-016, Issue 1, 84-03-23, "Preliminary Measurement of Compressor Sound Levels", by J.H. Stannard.
- 17: Dwg. No. 068-401-016, Rev. 0. "All Weather Operation Air Supply Control".
- 18: Dwg. No. 068-401-017, Rev. 0. "All Weather Operation Air Interconnect for Rail Joint".
- 19: Dwg. No. 068-401-018, Rev. 0. "All Weather Operation Alternate Manifold Air Supply".
- 20: Dwg. No. 068-401-026, Rev. 0. "Rail Joint/Air Valve Positioning In Cross Trenches".
- 21: Dwg. No. 068-401-001, Rev. A. "ETV Base".
- 22: Report No. 447-520-004, Issue 1, 84-01-25, "Transporter Vehicle Modification", by K.C. Falconer.
- 23: Report No. 447-520-015, Issue 1, 84-03-11, "Transporter Vehicle Suspension and Structural Deflections", by J.H. Stannard.
- 24: Dwg. No. 068-401-002, Rev. 0. "ETV - Shoe PU".



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- 27: Dwg. No. 068-401-015, Rev. 0. "ETV Assembly Details - Vehicle Suspension Shoe".
- 28: Dwg. No. 068-401-007, Rev. A. "Reaction Rail Details".
- 29: Dwg. No. 068-401-005, Rev. 0. "Reaction Rail Stiffener".
- 30: Dwg. No. 068-401-008, Rev. A. Sheet 2 of 2, "ETV Assembly Details - Reaction Rail".
- 31: Dwg. No. 68-401-009, Rev. 0. "Pickup Adapter Plate and Spacer".
- 32: Dwg. No. 68-401-027, Rev. 0. "Sensor Rail Details".
- 33: Dwg. No. 68-401-028, Rev. 0. "ETV Sensor Rail Installation".
- 34: Dwg. No. 068-401-006, Rev. 0. "Vehicle Link Details".
- 35: Report No. 447-540-007, Issue 1, 84-02-17, "Transporter Control Concept", by A. Kwasniewski.
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- 40: Report No. 447-530-010, Issue 1, 84-0-24, "Track De-Icing System", by J.H. Stannard.
- 41: Dwg. No. 68-201-009, Rev. 0. "Heater Installation".
- 42: TBD
- 43: Sullair Compressor Manual.
- 44: Report No. 584-TNR-207-004, 83-03-14, "Commissioning Test Plan", by J.H. Stannard.



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By

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PRELIMINARY FRICTION TEST
TEST AND VALIDATION

Report No.: 447-610-002

Date: 84 07 04

Prepared By:

Keith C. Falconer
Project Engineer

Approved By:

S. [Signature]
Project Manager



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SUMMARY

The preliminary test and validation of shoe to rail friction runs have been completed. It was evident that further operation of the system would contribute to additional polishing of the rail and subsequent reduction in drag.



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PURPOSE

To provide a preliminary result of shoe to rail friction relative to overall load of the vehicle.

PROCEDURE

- o Vehicle ETV#2 chassis without external load was used for the preliminary friction test.
- o Weight of empty chassis in running condition - 244 lbs.
- o Tracks were washed with water and wiped clean while air pressure was supplied to the drilled jets.
- o Air pressure was set at 17 p.s.i.g. at the rail holes. All sections registered the same pressure within readable limits using an oil damped Marsh Instrument Pressure Gauge Scale - 0 to 60 p.s.i.g.
- o A Hunter Force Gauge - Model D200M S/N 317 was used to tow the vehicle with a two metre rope held at an angle of 10-15 degrees from horizontal.
- o Several runs were made in each direction and the low and high readings for each section of "free" track were recorded.
- o Crossing the track rail joints presented very erratic readings due to air switching control. It is known that higher readings will result at the rail joints, but since air control across each joint had not been achieved at this date, the readings were deleted from the preliminary record.
- o The record is noted on a Friction Test Card as a part of this report.
- o A sketch of the track bed is shown in Figure 1.



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VEHICLE: E.T.V. #2 CHASSIS ONLY

RUN#: AVERAGE OF 4 TIME: 13:00 - 14:00

RAIL AIR PRESS: 17 P.S.I.G.

GAUGE: HUNTER FORCE GAUGE

LOAD: 244 LBS.

AMB. TEMP: +25 C

WIND - S/W LIGHT

SKY - CLEAR

SHOES: 24" ARTIC.'D

- TIGHT PACK

MODEL: D200M S/N 317

TRACK LOCATION - R&D/MCL

SECTION	EASTBOUND FORCE LB	WESTBOUND FORCE LB		HOLE PATTERN
B	72-75	72-75	NO AIR	S N
B	20-30	20-30	AIR "ON"	W
C	75-80	75-80	NO AIR	
C	20-30	20-30	AIR "ON"	
D	75-80	75-80	NO AIR	
D	22-30	20-30	AIR "ON"	
E	75-80	70-80	NO AIR	E
E	22-30	20-30	AIR "ON"	AT 6"
F	75-80	75-80	NO AIR	
F	22-30	20-30	AIR "ON"	
G	75-80	65-75	NO AIR	
G	22-30	20-28	AIR "ON"	

NOTES:

- o AIR "ON" FOR 9 SECONDS ON EACH SECTION
- o SHOES ARE HEAVILY SCRATCHED DUE TO CAR BEING MOVED ON DIRTY TRACK WITHOUT AIR
- o READINGS ACROSS RAIL JOINTS DELETED DUE TO AIR SWITCHING CONTROL RESTRICTIONS
- o SOME REDUCTION IN DRAG WAS NOTED AS TRACK BEGAN TO BE POLISHED
- o AVERAGE RESISTANCE - AIR "ON" - 25.6 LBS.



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Project
Transporter

Title
Preliminary Friction Test
Test and Validation

By
K.C.F.

Appd
JHS

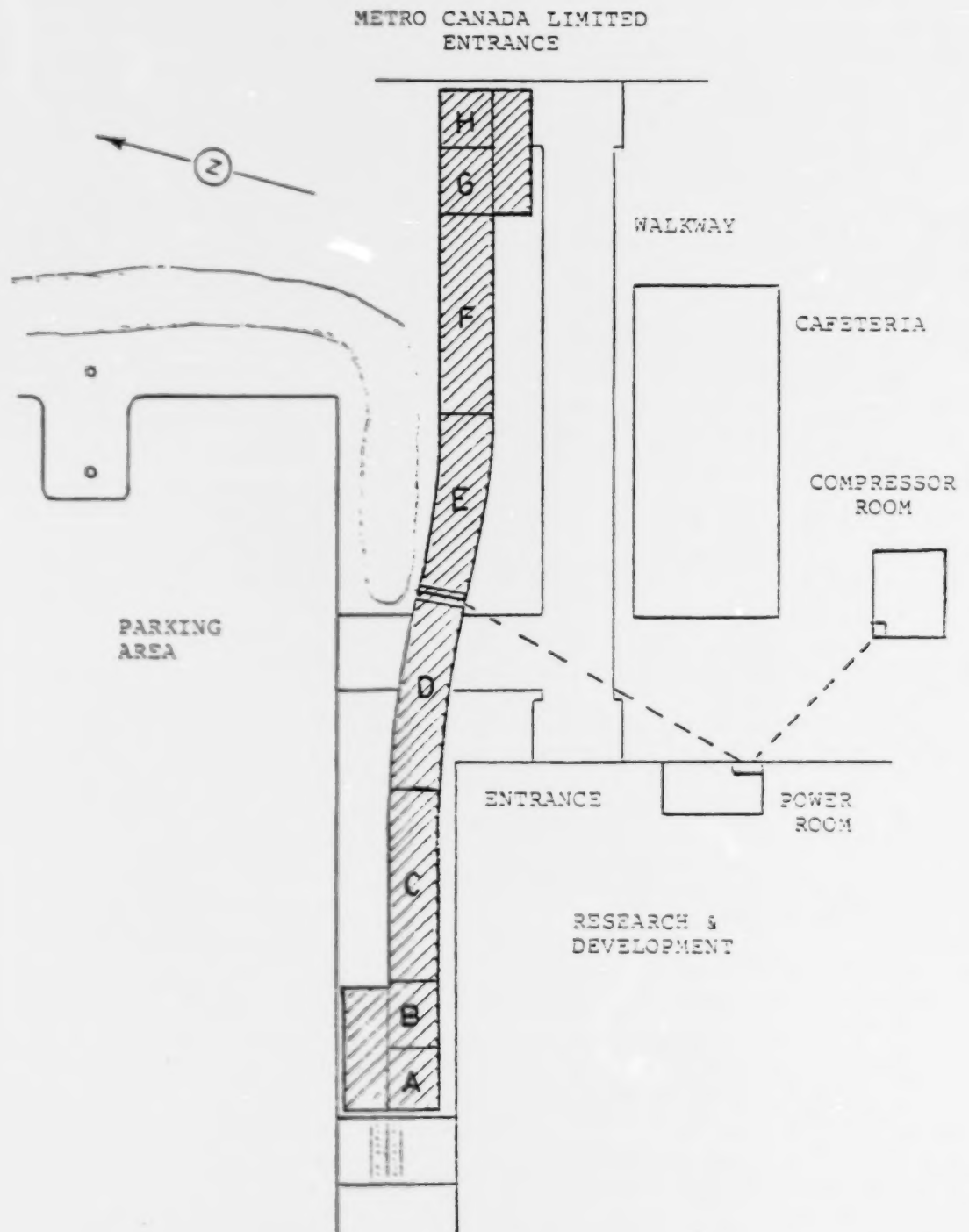


FIGURE 1: TRANSPORTER DEMONSTRATION TRACK LAYOUT



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CONCLUSION

The first of the preliminary friction tests has been completed. Further tests are required to record the reduction in friction following continuous polishing of the rail.



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Program Analysis
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By

K.C.F.

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JHS

TRANSPORTER

PROGRAM ANALYSIS

SYSTEMS INSTALLATION

Report No.: 447-610-004

Date: 84.07.09

Prepared By

Keith C. Falconer

Project Engineer

Approved By

S. J. J. J.

Project Manager



UTDC Research & Development Ltd.

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By K.C.F.		Appd JHS

Project Transporter	Title Program Analysis Systems Installation
------------------------	---

SUMMARY

A general analysis of the installation of the demonstrator Transporter is completed.

Problems, defects, design changes and recommendations are noted.



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1.0

PURPOSE

This report reviews the work plan and completed tasks of the Transporter demonstration link and comments on problems, corrections, design changes and recommendations.



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2.0 REVIEW BY TASK

2.1 TRACK DESIGN

Generally, track design as reviewed in Technical Analysis Note 447-510-001, was completed as programmed. Severe winter weather threatened delays and impacted the curing of the concrete. An "inclement weather" tent was constructed and propane heaters were used to thaw the ground site and to permit concrete work and subsequent curing.

Installation was completed satisfactorily with the exception of a number of minor deviations from design tolerances to the concrete forming. These variations were overcome by minor compromise to later installations - e.g. the trench ledges were not to the design dimension and necessitated adjustment to the thickness of the trench covers. The later work load was increased but completion of the installation was accomplished.

The concrete work was successfully carried out during the most severe weather of the winter season and the construction schedule is recorded in Appendix 1 of Technical Note 447-510-001.

A chronological order of events is as follows:

- 1) Weather Protection Unit: commence 1 January 1984, complete 5 January 1984 - in blowing snow
- 2) Concrete Formings: commence 6 January 1984, complete 18 January 1984



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- 3) Concrete Pours - Two Pours: #1 - 12 January 1984,
#2 - 18 January 1984
- 4) Strip Forms: commence 13 January 1984, complete
19 January 1984
- 5) Clean-Up Area: 20 January 1984
- 6) Curing Cycle: 19 January through 20 January 1984.

Completed on schedule.

Recommendations: Some changes in final road bed profile and track hold down methods are recommended for future installations. These changes would primarily be in the area of the profile of the centre of the concrete road bed and to the provision for increased drainage. Both of these changes would reduce the cost of an installation and the complexity of the profile. The additional drainage provision would provide for a dryer service trench following a heavy rain. Snow on the track was easily brushed off and did not affect a covered service trench but heavy rain could conceivably flood the trench to an unacceptable depth with little or no inducement for quick run-off.

The poor quality of the concrete surface, as evidenced by flaking, powdering, cracking, and breaking away when "Hilti" plugs were installed, would appear to be the result of intermittent freezing during the curing cycle: This indicates the need to plan for continuous extreme weather conditions, and preferably, to arrange for concrete pouring and forming during non-freezing weather. The track profile would also be much easier to produce in less severe weather and costs would be reduced.



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2.1.1 Rail Installation

Rails were prepared and installed as reviewed in Technical Analysis Note 447-510-008 with the exception of the track section end brackets which were lengthened to ensure adequate spanning of the cross trenches in the road bed. It was proven that no pre-bending or curving of the rail sections was required for the 72 metre curve but this would be close to the limit of the "hand formed" curves for track laying. Rapid changes in ambient temperature can cause considerable strain on the bulb angle brackets that were welded to the rails, resulting in a number of cracked welds.

Recommendations: It is recommended that additional "non-welded" brackets be installed, where indicated, after the rail is in place to relieve the strain on the welded brackets and to permit increased longitudinal movement.

An improved method of ensuring alignment of the butt-ends of each rail is also desirable. Currently, if a rail is to be replaced, adjacent rails must also be removed and the rail joint alignment does not always return to the position desired without considerable adjustment of the hold down clips. The removal and replacement of an individual rail without disturbing other rails could conceivably be required.

Improved control or distribution of air to the track manifold section is desirable and, an improved air control and distribution valve for the operation of the sequencing system could also be an asset. This is being reviewed.

The only remaining problem is that of "smoothness" of the roadbed. Although dimensions are generally within tolerance, short rough surfaced sections and changes in elevation caused problems in levelling the rail.



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2.1.2 Curving Capability

An analysis of curving capability was reviewed in Technical Analysis Note 447-520-013.

This concluded that the minimum curve radius with the existing shoe and suspension technology was limited to a value in the 60 metre to 80 metre order. The track installation indicated that a 72 metre curve could be achieved without excessive deformation of the rail profile and the rail could be pulled into place without pre-bending or pre-curving of the rails. Mechanical methods of forming a closer radius (such as jacking) might achieve a 70 metre value but the strain on the hold down clips is expected to be very high.

The drag rise in the 72 metre curve is acceptable based on preliminary tests and further tests during the commissioning phase will provide the exact numbers after the rail and shoes are conditioned.

2.1.3 Emergency Over-Run System

A passive emergency stopping system to prevent the vehicle over-running the track ends was designed and this is described in Technical Analysis Note 447-510-022. This system is capable of stopping the vehicle from 3.0 m/s, which is three times the design track speed of 1.0 m/s. Installation and adjustment were accomplished without problems.

2.2 VEHICLE MODIFICATION

2.2.1 Vehicle Interface

A vehicle interface with the track system was reviewed in Technical Analysis Note 447-510-003. This studied the requirements of modification to the existing chassis and



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vehicle body to provide for proper interface with the designed track way and road bed.

In order to reduce the "bending" of the reaction rail, new support pick-up points were required and some stiffening of the chassis was included. This is illustrated in drawing 68-401-001 Rev. C.

Some additional modification to the existing vehicle body was incorporated to permit entry and exit from both sides of the vehicle. A concealed compartment, suitable for carrying a battery and other accessories was incorporated in one end of the vehicle body (see Figure 1).

A weatherproof canvas tarpaulin secured by "DOT" fasteners was provided, pending the review of the desirability of a fully weatherproof canopy with doors, for this vehicle. The original body was not designed for permanent outside operation. The car body will not be installed until all other testing is complete and the demonstration cycle begins.



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DISNEY DISPLAY CAR MODIFICATIONS

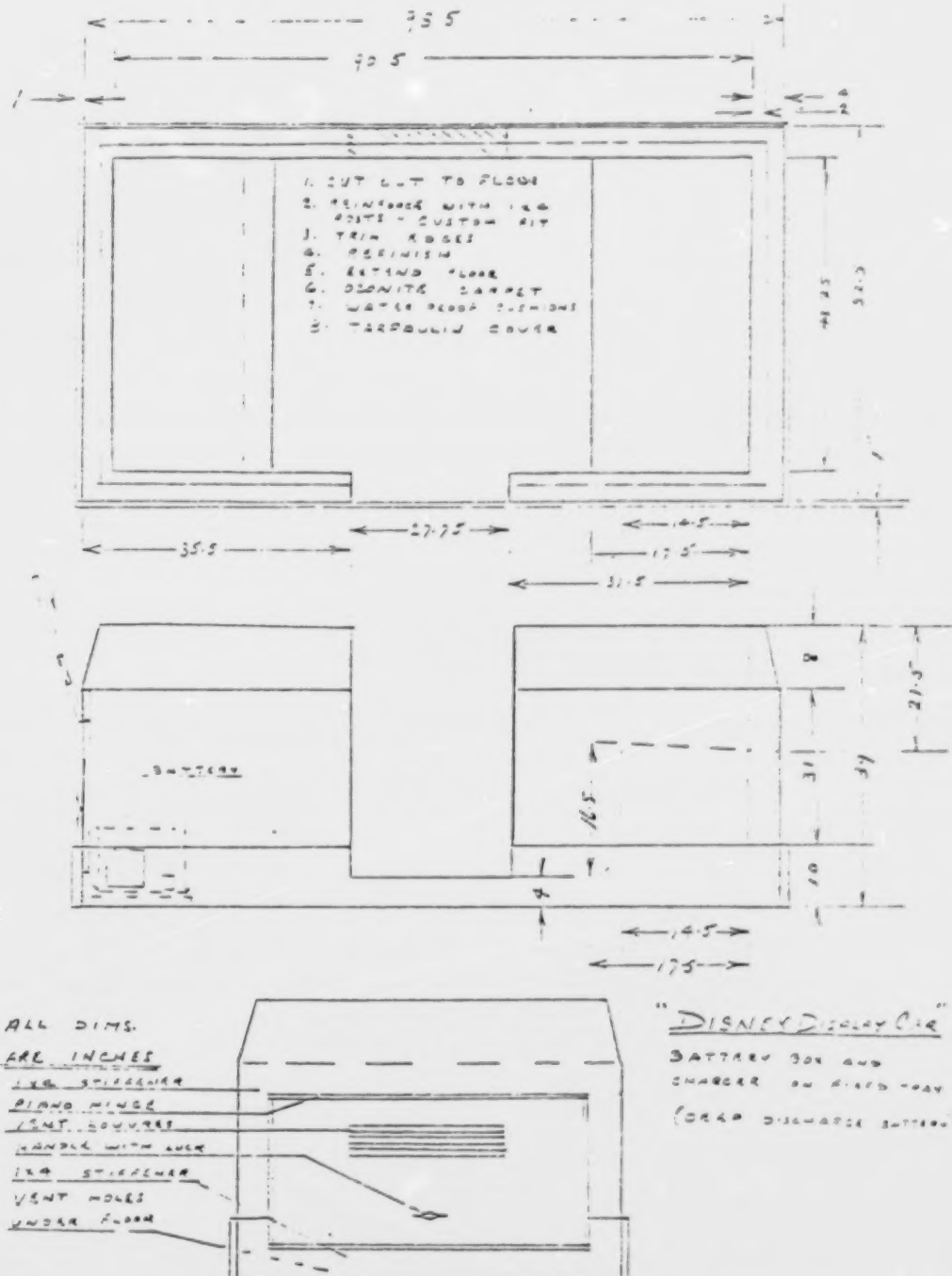


FIGURE 1



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2.2.2 Vehicle Suspension

Vehicle structural and suspension deflections were analysed in Technical Analysis Note 447-520-015. It was concluded that initial operation should be with solid swivel pins to give articulation of the shoe carriers, rather than rubber elements. It was also concluded that the reaction rail support and suspension pick-up points should be revised on the original chassis to reduce the structural deflections. This will permit a reduced air gap between the LIM and the reaction rail and improve the thrust.

The work was accomplished and the chassis is operational.

Drawing No. 068-401-008 Rev. B refers to the correct swivel mounting and drawing No. 68-401-001 Rev. C illustrates the chassis/reaction rail supports.

2.3 ALL WEATHER OPERATION

2.3.1 Development of Expansion Joint Design

In order to obtain leak proof air joints throughout a wide ambient temperature range, an all-weather rail expansion joint was designed. Drawing No. 068-401-024 refers. This is reviewed in Technical Analysis Note 447-530-006. It was concluded that welded, gas tight rail ends were superior to other joints for all-weather operation. After installation a number of leaks in the welds developed which had previously been disguised by welding slag. In total some 6 of 32 welded rail ends had to be reworked. In addition the tapped hole in the side wall is prone to leakage after several on-off cycles.

An improved method for maintaining butt end alignment in curves is under study and a method for changing individual rail sections without disturbing adjacent rail sections is under review.



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2.3.2 Track De-Icing System

A track de-icing system using heated air is reviewed in Technical Analysis Note 447-530-010 and the recommendations for installation of a hot air system were applied. The method is illustrated in drawing 68-201-009. A revision to the original concept moved the heater to the side of the track bed to make room in the cable trench for other details. Air plumbing was extended to suit.

The system was operated successfully for a limited period during drifting snow conditions and snow was easily softened in a few minutes of operation when the track temperature was increased by only a very small (un-measured) amount. Complete melting of the snow has not yet been demonstrated and further testing during actual severe inclement weather conditions is required.

2.4 AIR SYSTEM

2.4.1 Primary Air Supply

A design concept for the primary air supply delivered from a sound attenuated building and piped underground to the track site was developed and described in Technical Analysis Note 447-550-002. This resulted in a Plumbing Contractor Technical Note 447-550-012 which defined the installation of the air supply system. The system was installed and the building was insulated.



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2.4.2 Compressor Noise Reduction

Methods for reducing compressor noise were reviewed and recommendations for insulation of the compressor building were made in Technical Analysis Note 447-550-009. Subsequent preliminary sound measurements resulted in compressor sound levels well below the criteria of 69 dBA at the critical position as defined in Technical Note 447-550-016.

The system has been operating satisfactorily since start-up.

Maintenance requirements are extremely low, of order 2 to 4 hours per month and typically 10 minutes per start-up/shut down.

2.4.3 Programming of Air Supply

The delivery of the air supply to each section of the drilled portion of the rail is triggered by a sensing rail mounted on the vehicle chassis passing over a proximity switch mounted in the track bed at each LIM location so that air and LIM power are synchronized to the passing of the sensing rail. This is controlled by the Programmable Logic Controller described in Technical Note 447-540-014.

2.5 PROPULSION AND CONTROLS

2.5.1 Preliminary Conduit Selection

Wiring and power feed requirements is reviewed in Technical Analysis Note 447-540-005. The installation was successfully completed and spare conduits and control wires were included in the network during the excavation for the underground power feed conduits. Technical Analysis Note 447-540-011 refers.



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2.5.2 Propulsion and Control

An investigation of the potential of controlled supply frequency in LIM propulsion as it applies to speed regulation, was reviewed in Technical Analysis Note 447-540-001 and this led to the recommendation for the Propulsion Control System Technical Analysis Note 447-540-018.

2.5.3 A Transporter Control Concept

A review of a desirable Transporter control concept in Technical Note 447-540-007 resulted in the recommendation for, and the installation of, a Programmable Logic Controller (PLC), and a Frequency Controller.

2.5.4 Vehicle Operation Description

Technical Analysis Note 447-540-014 described the proposed vehicle operation and control and this was the basis for the PLC programming.

2.5.5 Automatic Operation

Automatic operation as well as manual operation of the system, and call, emergency safety stops and speed control have been "built in" to the control system and an observer in the control system mechanical equipment room can determine the location of the vehicle and condition of the system at any time.

The prospective rider may call the vehicle to his station at any time and the rest of the sequence is automatic.



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2.5.6

Emergency Stop

An emergency stop button is available for instant shut-down at each station. Once the emergency system is activated, all power and air is shut off from the track area and human intervention in the control system, in the mechanical equipment room, is necessary to re-activate the system. This is documented in the Vehicle Operation Description Technical Note 447-540-014.



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CONCLUSIONS AND RECOMMENDATIONS

The work plan and completed tasks have been reviewed, comments and recommendations are made during the reviews of each task and the commissioning of the system is underway.



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Integrated System Tests

By

J.H.S.

Appd

INTEGRATED SYSTEM TESTS OF TRANSPORTER DEMONSTRATION SYSTEM

REPORT NO.: 447-610-005

DATE: 84-07-20

PREPARED BY:

S.H.S.

APPROVED BY:

J. Stewart



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SUMMARY

Integrated system tests started 12 July 1984 with vehicle ETV2 without passenger carrying body. Initial problems with air and LIM sequencing were easily overcome by minor control software changes and mechanical changes to the sensor rail. The major problem area was mechanical interference between vehicle and track which required time consuming adjustment of many vehicle and track mounted items before quiet smooth operation was achieved.



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TEST CARDS



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1.0

PURPOSE

To report on integrated system tests carried out as part of the Transporter commissioning and make recommendations for future work.



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Integrated System Tests

2.0 GENERAL

2.1 INITIAL TESTS

In order to carry out integrated tests a series of other tests of particular systems and subsystems were carried out, following in general the "Test Plan" (Attachment 5.2). In some cases the initial testing revealed no significant problem areas, in others remedial measures (e.g. rail shimming, LIM rework) were required. These tests are summarized in Table 1.

Operation commenced with an unloaded vehicle in an easterly direction as recorded in the attached Test Cards (section 4), for Runs # 1 to 5. Vehicle operation was smooth and jerk-free but only progressed part of the way down the track. It was found that the edge of the notched sensor rail was incorrectly triggering the sensors. When the edge was relieved by 15 mm the vehicle then covered the entire track length (Runs # 6, 7, 8, 9).

2.2 BRAKING TESTS

A lack of braking action was observed in the initial test series, and a further set of tests was carried out to investigate the cause. The controls had been programmed to brake using a frequency near zero Hz but this was found to be ineffectual. The braking mode was changed to reverse thrust at a finite frequency. Braking action was much improved but control was not total, and the vehicle would "bounce" back from the correct position. A series of software modifications to the braking timing resulted in a reasonably successful set of tests (Run # 10 to 28) in which the overshoot was measured. The data was used to improve the braking algorithm but it was eventually concluded that with wide variations in speed entering the station, it would be impossible to correctly set braking distance and stopping position. This



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SYSTEM	SECTIONS IN COMMISSIONING TEST PLAN	NATURE OF TEST	DOCUMENTATION REQUIRED	STATUS 84.07.20	PLANNED ACTION TO COMPLETE
SITE, SLABS AND TERMINALS	3.1, 4.1, 5.1	Visual Inspection and Physical Measurements	Test Report and Marked up Drawings	Visual Inspection Complete	Mark up Drawings
TRACK Individual Rails Rails as a Pair	3.2.1, 4.2.1, 5.2.1 3.2.2, 4.2.2, 5.2.2	Visual Inspection and Comparison with Special Gauges	Test Report and Marked up Drawings	Visual Inspection Complete	Shim and Adjust to meet Specifications
WIRING Power Wiring Controls Wiring	3.3.1, 4.3.1, 5.3.1 3.3.2, 4.3.2, 5.3.2	Check Continuity, Identification and Insulation	None	Complete	None
SENSORS	3.4, 4.4, 5.4	Check Operation	None	Complete	None
AIR SYSTEM Compressor Distribution & Control	3.5.1, 4.5.1, 5.5.1 3.5.2, 4.5.2, 5.5.2	Observe and Measure Operation, Performance, Noise and Thermal	Noise and Performance Reports and Operating Instructions	Noise and Operational Aspects Complete	Complete Performance Test and Thermal Test
VEHICLES General Base Shoes & Suspension LIM Secondary Sensor Rail Vehicle Link Integrated Vehicle	3.6.1, 4.6.1, 5.6.1 3.6.2, 4.6.2, 5.6.2 3.6.3, 4.6.3, 5.6.3 3.6.4, 4.6.4, 5.6.4 3.6.5, 4.6.5, 5.6.5 3.6.6, 4.6.6, 5.6.6 3.6.7, 4.6.7, 5.6.7	Visual Inspection and Physical Measurements where required	Marked up Drawings and Data for Integrated Vehicle tests	In Progress	Complete tests and Documentations

Table 1



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SYSTEM	SECTIONS IN COMMISSIONING TEST PLAN	NATURE OF TEST	DOCUMENTATION REQUIRED	STATUS 84.07.20	PLANNED ACTION TO COMPLETE
FRICTION	3.7, 4.7, 5.7	Measure Vehicle/Track Friction	Test Reports 447-610-002 and 007	Preliminary Complete	Tests Repeat after Polishing
CONTROL SYSTEM User Controls Non-User Controls	3.8.1, 4.8.1, 5.8.1 3.8.2, 4.8.2, 5.8.2	Investigate action of all devices	Operations Description	Partially Complete	Write Operational Instructions
HEATER	3.9, 4.9, 5.9		Test Reports	Preliminary Complete	Delay to Winter
FREQUENCY INVERTER	3.10, 4.10, 5.10	Test Functions Separately	None	Complete	None except for Monitoring
LOGIC CONTROL UNIT	3.11, 4.11, 5.11	Test each Algorithm Separately	None	Complete	None except for Monitoring
LIM's	3.12, 4.12, 5.12	Thrust Direction, Mounting and Insulation	Test Report 447-610-005	Complete	Monitor Condition and Rework if Necessary
INTEGRATED SYSTEM	3.13, 4.13, 5.13	Investigation of all Aspects of Normal Vehicle Operation and Emergency Cases	Test Report 447-610-005 and Additional Reports	Initial Tests Complete	Investigate Braking and Speed Control and Document

Table 1: Continued

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speed variation was a result of carrying out the tests without the speed control system, which will be developed at the earliest opportunity.

2.3 EMERGENCY STOP TEST

The emergency stop system was tested at a vehicle speed of approximately 2 m/sec and found to stop the vehicle in a distance of 3 m. All power and air to the track was shut-off leaving the system in a safe condition. The only problem arising was a lengthy period to restore the control system after shut-down. The software will be modified to allow a manual restart with more ease.

2.4 VEHICLE-TRACK INTERFERENCE

Throughout the above tests, and other tests carried out to investigate various aspects of the control system and tracks polishing effects (run numbers 28 to 63) there were occasions when either the sensor rail or reaction rail struck the concrete or LIM upper surface. On investigation, it was found that this was due to a number of reasons:

- o LIM downforce compressing suspension,
- o shoe creep allowing gap setting smaller than specified,
- o incorrectly installed paving slabs,
- o 2 LIMs set too high relative to rail.

Remedial action included re-setting the reaction rail and other hardware. A longer-term action is manufacture of an improved reaction rail with a better ratio of longitudinal to normal force.



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CONCLUSIONS AND RECOMMENDATIONS

The integrated system tests have resulted in a number of positive accomplishments:

- o safe vehicle operation at speeds between 1.0 and 3.0 m/sec at low vehicle mass,
- o smooth jerk-free acceleration, cruise and stopping,
- o operation at 1.0 m/sec at 50% payload,
- o correct sequencing of air and propulsion systems,
- o correct detection of vehicle position by notched sensor rail and proximity sensor,
- o safe emergency stop

The remaining testing and demonstration will refine operation rather than cover new ground. Factors to be improved are:

- o Vehicle-Track Interference
- o Speed Control
- o Stopping Position



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Integrated System Tests

4.0

INTEGRATED TESTING - TEST CARD

Date: 84.07.11

Test Personnel: KCF, AK, JHS

Time: 17:30 to 18:00

Vehicle: ETV #2

Weather: Overcast, Warm
High Humidity

Reaction Rail Gap: 9.5 mm Empty

Run #	Direction	Nominal Hz	Nominal Volts	Vehicle Mass Kg	Comments
1	E	25	120	111	Insufficient Thrust Air Incorrectly Manually Switched
2	E	25	150	111	Sufficient Thrust Smooth Acceleration Steady Speed Achieved LIMs and Air Not Correctly switched after LIM #6 Sensor Rail Scraping
3	E	25	150	111	Vehicle accelerated smoothly and got to crossing with manual air selection Logic Unit Errors LIMs quiet Initial positive setting EXTREMELY DIFFICULT



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By

J.H.S.

Appd

Project

Title

Transporter

Integrated System Tests

INTEGRATED TESTING - TEST CARD

Date: 84.07.12

Test Personnel: KCF, AK, JHS

Time: 13:00 to 18:00

Vehicle: ETV #2

Weather: Sunny, Intermittent
Overcast
High Humidity

Reaction Rail Gap: 9.5 mm Empty

NOTE: A number of unnumbered partial runs were carried out without recording data in effort to debug control system.

Run #	Direction	Nominal Hz	Nominal Volts	Vehicle Mass Kg	Comments
4	E	25	150	111	Sensor Rail Scraping Vehicle Stops at LIM #7 LIM #s 7 and 8 and next air section (D) not activated.
5	E	25	150	111	Repeat of above vehicle Position Difficult to set. Note: After considerable investigation, it was found that the edge of the sensor bar was activating sensor inadvertently and thus logical unit was losing vehicle position.



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INTEGRATED TESTING - TEST CARD

Date: 84.07.13

Test Personnel: KCF, AK

Time: 10:00 to 17:00

Vehicle: ETV #2

Weather: Sunny, Some Overcast

Reaction Rail Gap: 9.5 mm Empty

NOTE: Shoes hard packed 24" on solid swivels.

Run #	Direction	Nominal Hz	Nominal Volts	Vehicle Mass Kg	Comments
6	E	22	150	111	Whole track covered. No braking observed.
7	E	22	150	111	Whole track covered. No braking observed.
8	W	22	150	111	Whole track covered. No braking observed.
9	W	22	150	111	Whole track covered. No braking observed.



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Transporter

Integrated System Tests

INTEGRATED TESTING - TEST CARD

Date: 84.07.16

Test Personnel: KCF, AK, JHS

Time: 9:00 to 17:00

Vehicle: ETV #2

Weather: 24°C, Sunny

Reaction Rail Gap: 9.5 mm

NOTE: Hard Pack shoes, 24", solid swivel

Run #	Direction	Nominal Hz	Nominal Volts	Vehicle Mass Kg	Comments
10	W	22	150	111	Checking Braking Distance
11	E	22	150	111	Checking Braking Distance
12	W	22	150	111	Checking Braking Distance
13	E	22	150	111	Checking Braking Distance
14	W	22	150	111	Checking Braking Distance
15	E	22	150	111	Some interference - Sensor to concrete
16	W	22	150	111	20" Overrun R&D - 24" - MCL
17	E	22	150	111	
18	W	22	150	111	20" Overrun R&D - 26" - MCL 26" Track Polishing



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Transporter

Integrated System Tests

INTEGRATED TESTING - TEST CARD

Date: 84.07.16

Test Personnel: KCF, AK

Time: 9:00 to 17:00

Vehicle: ETV #2

Weather: 24°C, Sunny

Reaction Rail Gap: 9.5 mm

NOTE: Hard Pack shoes, 24", solid swivel

Run #	Direction	Nominal Hz	Nominal Volts	Vehicle Mass Kg	Comments
19	E	22	150	111	Power off at #18 LIM overshoot 36"
20	W	22	150	111	Power off at #3 LIM overshoot 48"
21	E	22	150	111	Zero frequency at #18 LIM overshoot as before.
22	W	22	150	111	Same overshoot - Track Polishing
23	E	22	150	111	Same Overshoot - some R.R. track on concrete.
24	W	22	150	111	Same as above.
25	E	22	150	111	Shoes bouncing at E-F joint track high at this joint.



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INTEGRATED TESTING - TEST CARD

Date: 84.07.16

Test Personnel: KCF, AK

Time: 9:00 to 17:00

Vehicle: ETV #2

Weather: 24°C, Sunny

Reaction Rail Gap: 9.5 mm Empty

NOTE: Hard Pack shoes, 24", solid swivel

Run #	Direction	Nominal Hz	Nominal Volts	Vehicle Mass Kg	Comments
26	W				Still overshoot.
27	E				Braking to zero freq. set at #4 LIM reduced overshoot.
28	W				Braking and zero freq. set at #17 LIM reduced overshoot.
29	E				Pulled by hand--drag check.
30	E				LIMs 16-17-18-19-20-21 in reverse mode - vehicle bounced back at #16.
31	W				LIMs 4-3-2-1 in reverse mode Vehicle bounced back at #4 LIM



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INTEGRATED TESTING - TEST CARD

Date: 84.07.16

Test Personnel: JHS, KCF, AK

Time: 9:00 to 17:00

Vehicle: ETV #2

Weather: Sunny, Warm

Reaction Rail Gap: 8 to 9 mm
Empty

NOTE: Hard Pack shoes, 24", solid swivel

Run #	Direction	Nominal Hz	Nominal Volts	Vehicle Mass Kg	Comments
32	E				As above.
33	W				As above.
34	E				Original mode - speed reduced vehicle overshoot only 6" - 10"
35	W				
36	E				
37	W				
38					No specific record - further cycles by electronics tech. for testing and adjustment purposes.
39					



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Transporter

Integrated System Tests

INTEGRATED TESTING - TEST CARD

Date: 84.07.17

Test Personnel: KCF, JHS, AK

Time: 8:15 to 17:00

Vehicle: ETV #2

Weather: Sunny, Warm

Reaction Rail Gap: 11 mm Empty

NOTE: Hard Pack shoes, 24", solid swivel

Run #	Direction	Nominal Hz	Nominal Volts	Vehicle Mass Kg	Comments
40	E	22	150	111	Reaction rail & sensor rail touching concrete at several positions - slabs removed for rework. Chassis raised by 1.5 mm. to raise reaction rail.
41	W	22	150	111	
42	E	22	150	111	
43	W	22	150	111	Check run - no rubs. Very quick - speed too high 2 m/sec 4 rail weights added
44	E	22	150	255	
45	W	22	150	255	Check runs - no shock bounce - much smoother run
46	R	22	150	255	Freq. reduced.
47	W	22	150	255	Check run - spread 1 m/sec & slabs installed.



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INTEGRATED TESTING - TEST CARD

Date: 84.07.17

Test Personnel: JHS, KCF, AK

Time: 9:00 to 18:00

Vehicle: ETV #2

Weather: Sunny, Warm

Reaction Rail Gap: 11 mm Empty

NOTE: Hard Pack shoes, 24", solid swivel

Run #	Direction	Nominal Hz	Nominal Volts	Vehicle Mass Kg	Comments
48	R	22	150	255	Check run - rubs-slabs
49	W	22	150	255	Removed
50	R	22	150	255	Check run
51	W	22	150	255	Check run
52	R	22	150	255	Demo for TDC Video Taping
53	V	22	150	255	
54	R	22	150	255	
55	W	22	150	255	
56	R	22	150	255	
57	W	22	150	255	



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INTEGRATED TESTING - TEST CARD

Date: 84.07.17

Test Personnel: KCF, AK

Time: 9:00 to 18:00

Vehicle: ETV #2

Weather: Sunny, Warm

Reaction Rail Gap: 11 mm Empty
Reducing due
to creep
during
tests

NOTE: Hard Pack shoes, 24", solid swivel

Run #	Direction	Nominal Hz	Nominal Volts	Vehicle Mass Kg	Comments
58	E	22	150	255	Demo for TIDC CA VERSAILLES
59	W	22	150	255	
60	R	22	150	255	
61	W	22	150	255	
62	R	22	150	255	
63	W	22	150	255	Air gap reduced to 6 mm at 255 kg.



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LIM
Insulation System Test

By

A.K.

Appd

S H S

LIM

INSULATION SYSTEM TEST

Report No.: 447-610-006

Date: 84.07.19

Prepared By

M. M. M. M. M.
Project Engineer

Approved By

S. S. S. S. S.
Project Manager



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LIM
Insulation System Test

By

A.K.

Appd

JHS

SUMMARY

A LIM Insulation Test was completed as a part of the Commissioning Test Plan. Measurements included Insulation Resistance of the LIM's Power Wiring. A number of LIM's were found to have unacceptable insulation when wet and were rewound.



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LIM
Insulation System Test

By

A.K.

Appd

JHS

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PURPOSE

The LIM Insulation System Test, as well as the whole of the Transporter System Electrical Insulation, was completed in order to be sure the System works safely at 208 volts, 3 phase.



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LIM
Insulation System Test

By

A.K.

Appd

JHS

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MEASUREMENTS AND METHODS

Insulation Resistance was measured with 500 V inductive megohm meter "MEGGER". Tests were repeated with the LIM's wet and in some cases when heated to operating temperature.



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LIM
Insulation System Test

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LIM'S ALLOCATION ON THE TRACK

LIM No.	1 - 3, 19 - 21	4, 18	5, 17	6 - 16
Type of LIM	Hoover No. 3	Hoover No. 2	Hoover No. 1	Nor-Mag
Wiring Set	Y	D	Y	Y

TABLE 1: LIM Arrangement on Track



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FIRST STAGE RESULTS

LIM NO.	LIM TYPE	Insulation Resistance								M					
		TOTAL		Phase to Phase						Phase to Ground					
				A-B		B-C		C-A		A		B		C	
		Wet	Dry												
1	H	150	150												
2	H	20	150												
3	H	30	150							12	∞	>150	∞	>150	∞
4	H	150	150												
5	H	5	150							>150	∞	8	∞	>150	∞
6	NM		0, 4		3		3, 5		4		2, 5		1, 4		3, 5
7	NM		0,09		42		>150		>150		40		0,08		>150
8	NM	15	20												
9	NM		4												
10	NM		0, 3								0, 6		0, 8		1, 5
11	NM		1, 5								150		2		5
12	NM		0, 5								150		150		0, 6
13	NM		0,12								3, 5		0,14		150
14	NM		0, 3								100		0,35		2
15	NM	0, 6	25							0, 7	1	13	25	2	3
16	NM	3, 5	16							50	150	30	70	12	28
17	H	50	>150							>150	>150	35	>150	>150	>150
18	H	3	>150												
19	H	30	>150												
20	H	2	>150												
21	H	10	>150												

TABLE 2: Insulation Resistance Measurements

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CONCLUSION FROM THE FIRST STAGE

LIM's #6, 7, 9, 10, 11, 12, 13 and 14 had un-acceptable insulation resistance*. They were sent to Ainsworth Electric Company for rework with the instruction that if the insulation resistance increased up to at least 5 M Ω after drying, the LIM's should be repotted only, if not, should be rewound. After heating it was found that only one LIM (#9) could be improved sufficiently by baking. As a result 7 LIM's were completely stripped, rewound, dipped twice and repotted in Epoxy. LIM #9 was merely repotted after drying.

The LIM's were then retested hot, cold and wet in various combinations at the factory and found to be satisfactory.

*NOTE

These LIM's had been operated in an outdoor environment successfully for 3 months but then stored for 12 months. A possible explanation for the problems is trapped water in the windings.



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INSULATION CHECKOUT AFTER RE-WINDING

All rewound LIM's kept the insulation resistance better than 150 M Ω whether they were dry or wet.

Repotted LIM #9 kept insulation resistance 5 M Ω dry and wet.

Further tests were carried out, shown in Table 3: after reinstallation in the test track and operating the system for one hour under power. The results indicate that most of the LIM's are now satisfactory.

LIM #s 5,15 and 16 which were not reworked initially are marginal, especially wet, and should be reworked at the earliest opportunity.



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A.K.

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LIM NO.	LIM TYPE	Insulation		Resistance M		NOTES
		Day Before Switching On the System	After Heavy Rain	After Few Hours of Sunny Period	Next Day, Morning	
1	H	∞	∞	∞	∞	
2	H	∞	150	∞	150	
3	H	∞	12	∞	150	
4	H	∞	150	∞	∞	
5	H	4	2	∞	∞	
6	NM	∞	150	∞	∞	Rewound
7	NM	∞	150	∞	∞	Rewound
8	NM	19	20	25	20	
9	NM	∞	150	∞	∞	Rewound
10	NM	25	30			Rewound
11	NM	4,5	4	5	4	Repotted (#9 before)
12	NM	100	30	∞	∞	Rewound
13	NM	∞	150	∞	∞	Rewound
14	NM	∞	1	∞	∞	Rewound
15	NM	1	0,7	1,3	1,0	
16	NM	9	7,0	20	9,0	
17	H	∞	30	∞	∞	
18	H	∞	100	∞	150	
19	H	∞	150	∞	∞	
20	H	8	10	∞	150	
21	H	50	20	∞	100	

TABLE 3: Insulation resistance after first period of operation under power (about one hour of system operation).



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LIM
Insulation System Test

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CONCLUSIONS AND RECOMMENDATIONS

- o LIM's insulation resistance should be recorded especially after very heavy rain.
- o The insulation of LIM's # 5, 15 and 16 has not been sealed and should be reworked as soon as possible.
- o LIM's weather protection or insulation system should be reviewed for the future application. Factors that must be investigated include:
 - Effect of interactions between varnish dipping and epoxy potting.
 - Method of epoxy potting.
 - Possibilities of protective box.



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Repeat Friction Tests

By JHS

Appd

REPEAT FRICTION TESTS

Prepared By

JHS

Approved By

[Signature]



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Repeat Friction Tests

By

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SUMMARY

The resistance coefficient between vehicle and rail was measured using a spring type force gauge. The resistance levels were lower than in tests carried out previously, the differences being attributed to rail polishing and shoe conditioning effects.



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Transporter

Repeat Friction Tests

By

JHS.

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PURPOSE

Previous preliminary test results indicated that the resistance to motion of the vehicle was extremely high. The track and shoes have since been carefully cleaned and the vehicle operated for approximately 50 runs. The purpose of this test is to establish the new levels of resistance.



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PROCEDURES

The procedure previously developed was used, but with a zero angle between towing rope and vehicle. (447-610-002)



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RESULTS

The raw test data is given on the test card (Section 5.). The results are expressed in resistance coefficient form in Table 1 below and compared to the results obtained in 447-610-002. A large decrease in friction is evident at all points on the track, largely as a result of track polishing and shoe conditioning. The rail was visibly more polished after the 50 runs. The value expected (admittedly at higher vehicle mass when shoe to track sealing is improved) is of order 0.045.



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TRACK SECTION (See 447-610-002)	POSITION RELATIVE TO LIM	NOTES	RESISTANCE	COEFFICIENT
			THIS TEST	447-610-002
B	2	Straight	0.029	0.102
B-C	3	Joint-Front Shoes	0.107	-
B-C	3	Straight	0.025	-
B-C	4	Joint-Rear Shoes	0.164	-
C	5	Straight	0.061	-
C	6	Curved	0.049	0.102
C	7	Curved	0.086	-
C-D	7	Joint-Front Shoes	0.127	-
C-D	7	Curved	0.066	-
C-D	7	Joint-Rear Shoes	0.123	-
D	8	Curved	0.074	-
D	8-9	Curved	0.049	-
D	9	Curved	0.066	0.105
D	10	Curved	0.082	-
D	11	Virtually Straight	0.098	-
D-E	11	Joint-Front Shoes	0.082	-
D-E	11	Joint-Rear Shoes	0.074	-
E	12	Curved	0.082	-
E	12-13	Curved	0.057	-
E	13	Curved	0.057	0.105
E	13-14	Curved	0.049	-
E	14	Curved	0.049	-
E	14-15	Curved	0.090	-
E-F	14-15	Joint-Front Shoes	0.115	-
E-F	15	Joint-Rear Shoes	0.148	-
F	15-16	Curved	0.098	-
F	16	Curved	0.074	-
F	16-17	Virtually Straight	0.086	0.105
F	17	Straight	0.090	-
F	17-18	Straight	0.074	-
F	18	Straight	0.082	-
F-G	19	Joint-Front Shoes	-	-
G	-	-	-	0.102

TABLE 1: COMPARISON OF TEST RESULTS



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JHS.

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Repeat Friction Tests

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CONCLUSIONS AND RECOMMENDATIONS

The resistance coefficient levels are much decreased from the previous levels. This effect is expected to continue. After 2 weeks of vehicle operation the resistance levels should be measured at a number of vehicle weights. The track joints are in some cases badly out of alignment. This should be adjusted before further tests.



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Transporter

Repeat Friction Tests

By

JHS.

Appd

VEHICLE ETV #2

LOAD /lb 244

RUN # One run

TIME 15.00

AMB. TEM. +25°C

Sunny

RAIL AIR PRESS

17 psi

SHOES

24" ART'D tight pack

GAUGE

Hunter Force Gauge

MODEL D 200 M S/N 317

SECTION	EASTBOUND FORCE /LB	LOCATION RELATIVE TO LIMS	COMMENTS
B	6-8	LIM 2	
B-C	26	LIM 3	JOINT - FRONT SHOES
B-C	6	LIM 3	SHOES STRADDLE JOINT
B-C	40	LIM 4	JOINT - REAR SHOES
C	10-20	LIM 5	STRAIGHT TRACK
C	14-12-10	LIM 6	REDUCING PRIOR TO JOINT
C-D	26-16	LIM 7	JUST PRIOR TO JOINT
C-D	30-16	LIM 7	FRONT SHOES ON JOINT
C-D	16	LIM 7	JUST PRIOR TO JOINT
C-D	30	LIM 7	FRONT SHOES ON JOINT
D	18	LIM 8	STRADDLE JOINT
D	12	LIM 8-9	REAR SHOES AT JOINT
D	16	LIM 9	
D	20	LIM 10	
D	24	LIM 11	JUST PRIOR TO JOINT
D-E	20	LIM 11	FRONT SHOES AT JOINT
D-E	18	LIM 11	REAR SHOES AT JOINT
E	20	LIM 12	
"	14	LIM 12-13	
"	14	LIM 13	
"	12	LIM 13-14	
"	12	LIM 14	
"	22	LIM 14-15	APPROACHING JOINT
E-F	28	LIM 14-15	FRONT SHOES AT JOINT
E-F	36	LIM 15	REAR SHOES AT JOINT
F	24	LIM 15-16	SOME WATER AT HOLES
F	18	LIM 16	
F	21	LIM 16-17	
F	22	LIM 17	
F	18	LIM 17-18	
F	20	LIM 18	
F-G		LIM 19	JOINT NO AIR
AVERAGE RESISTANCE			18.75 LBS



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84.03.23

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Transporter

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Preliminary Compressor
Sound Levels

By

J.H.S.

Appd

PRELIMINARY MEASUREMENTS OF COMPRESSOR SOUND LEVELS

Report No.: 447-550-016

Date: 84.03.23

Prepared By J. H. STANNARD
Project Engineer

Approved By W. Beech
Project Manager



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Report No

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Project

Transporter

Title

Preliminary Compressor
Sound Levels

By

J.H.S.

Appd

SUMMARY

Preliminary measurements indicate that the compressor acoustic treatment has successfully met the criteria of 69 dBA at the Cafeteria steps with a measured level of 57 dBA at that location. The system is inaudible in the cafeteria and offices. The periodic venting of the drier system can just be heard in the cafeteria.



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PURPOSE

To measure sound pressure levels around the compressor hut during compressor operation and compare the values to the requirement for 69 dBA at the Cafeteria Steps.



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TEST PROCEDURE

A hand-held integrating sound level meter was pointed towards the hut from the locations marked on Figure 1 and the sound levels measured using the "slow" setting provided to avoid recording peaks due to passing traffic. The meter was held 1.2 m above ground level.



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TEST APPARATUS

Bruel and Kjaer Sound Level Meter

Type 2226

UTDC Ltd. Serial No. 400455

Calibrated February '84

Calibration Expires February '85

Readings directly in dBA



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TEST RESULTS

Sound levels are shown in their respective locations in Figure 1. If the compressor was running under full load these levels might be slightly increased (Approx. 3 dBA) but will not exceed the criteria set.

The compressor is inaudible in the cafeteria and all offices. Operation with the recirculation flap 75% open stabilised compressor hut temperature to approximately 15°C.

A more thorough set of measurements should be made as part of commissioning.



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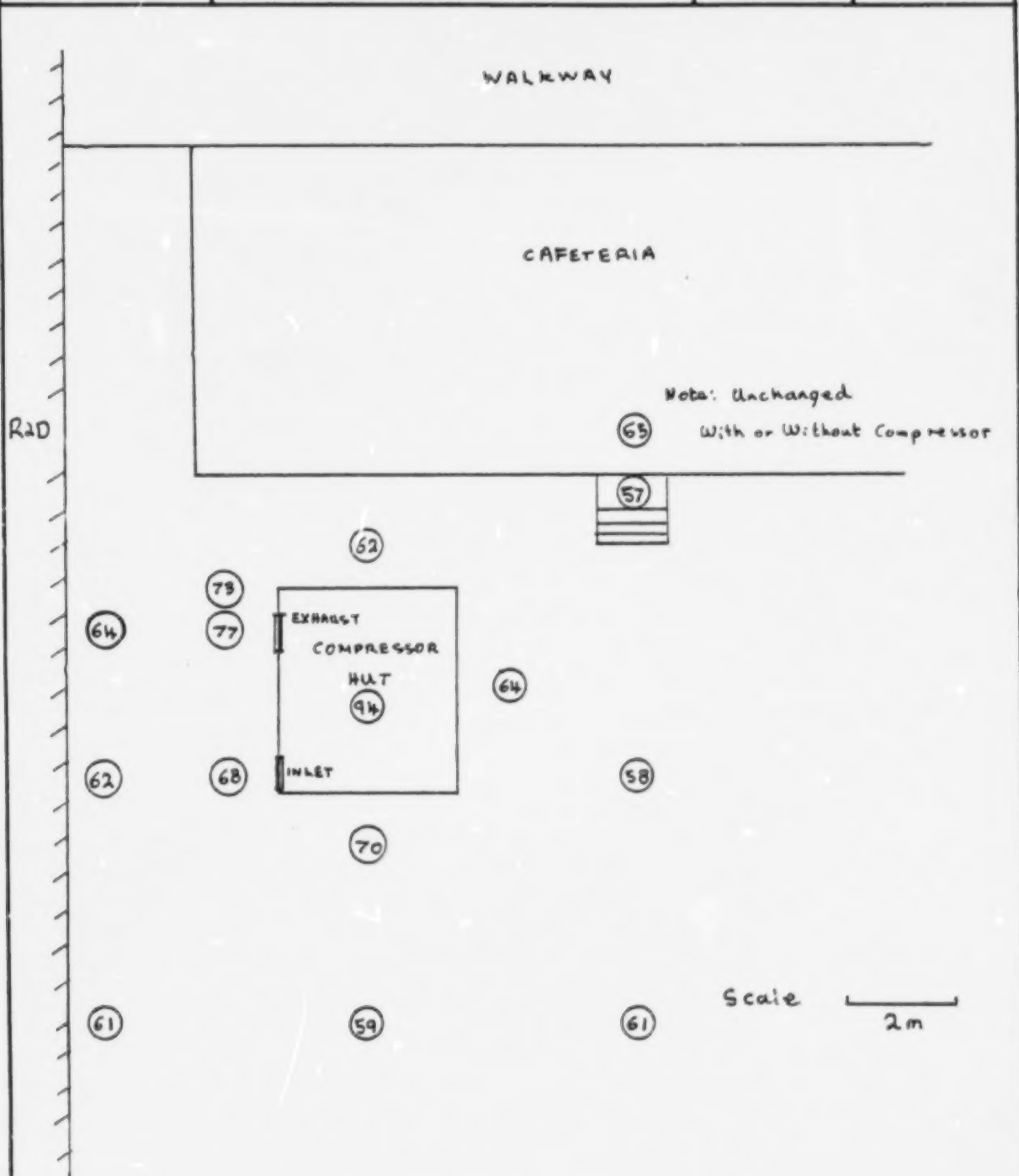


FIGURE 1: SOUND LEVEL MEASUREMENTS: dBA

A8

DEVELOPMENT OF AN
AIR BEARING TRANSPORTATION SYSTEM
MILESTONE NO. 4 REPORT

SUBMITTED TO: TRANSPORTATION DEVELOPMENT CENTRE
CONTRACT SERIAL NO: OSD83-00047



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Transporter

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MILESTONE NO. 4 SUMMARY

DEMONSTRATION TRACK

DAILY OPERATION

Report No.: 447-900-040

Date: 84.10.31

D.S.S. Contract Serial No. OSD83-00047

Prepared By

Keith C. Deane

Approved By

S. Howard



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MILESTONE REPORT #4

SUMMARY

The construction of the demonstration track began 28 December 1983, and the demonstration phase of daily operation began on 1 August 1984. The system has been demonstrated to T.D.C., and 35 mm slides and video tape are provided to illustrate operation of the system. Updating of the computer to provide additional control memory for all ambient temperature and humidity conditions is recommended. A total of 42,550 one-way trips was completed by the end of the 3 month demonstration on 31 October 1984.



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35 mm Slides of System

V.C.R. Video Cassette

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1.0

PURPOSE

This report records the operational results of the demonstration phase.

The demonstration phase commenced on 1 August 1984 when the system was considered to be satisfactorily operational. Prior to this phase, some 800 one-way trips were completed during the commissioning phase.



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2.0 REVIEW OF WORK CARRIED OUT

2.1 LOG BOOK

At the conclusion of the commissioning phase, which was reported as Milestone #3, a daily log was raised in order to record any changes, defects, accomplishments, repairs and actual running trips and training times.

The log also recorded such daily information as current weather, stops planned or unplanned, changes to the computer program, unusual incidents, e.g., failure of the frequency inverter, adjustments and official demonstration runs.

2.2 PLAN OF OPERATION

The plan of operation for the demonstration program was to commence running at the regular starting time for each day and to break into the operation when required for the purpose of providing demonstration rides or to gather test data as necessary, e.g., friction tests. Accumulated experience indicated that riders could board the vehicle in either station at any time, except during special tests, and all UTDC personnel and visitors were encouraged to do so.

Apart from a number of failures to some of the equipment which reduced the daily running time, this plan was adhered to throughout the demonstration phase and, as the learning curve progressed and service failures were reduced, the number of trips increased dramatically. A chart of the weekly operations is shown in Figure 1.



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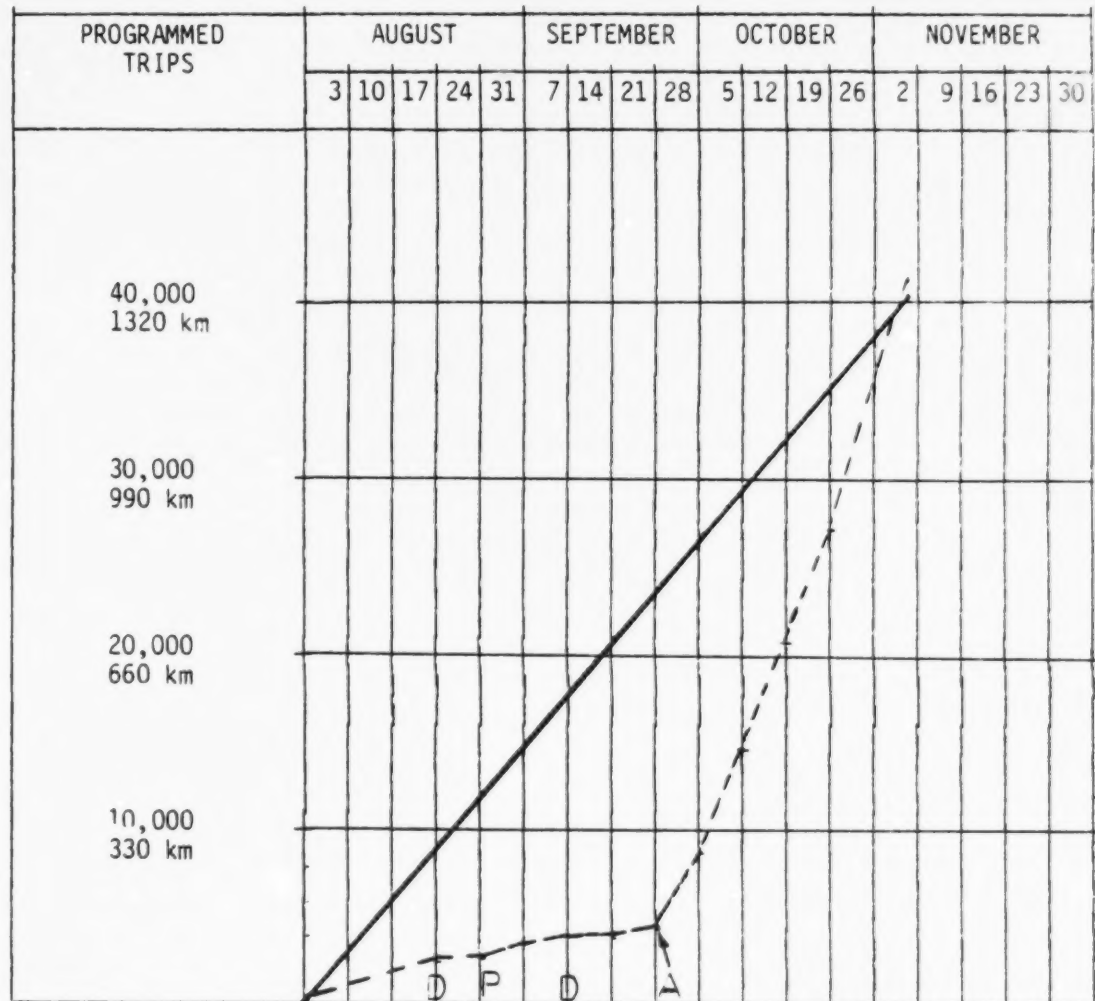


FIGURE 1: TRANSPORTER DEMONSTRATION TESTING

TARGET: 8 hrs/day operation for 63 working days

D - Drive Failure
A - Automatic Operation
P - Power Failure

————— Planned

----- Actual



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2.3 PERFORMANCE EVALUATION

The continuous operation plan provided a method of assessing the performance of the system. A number of anomalies occurred and several commercially supplied item defects required special attention.

2.3.1 Track and Track Bed

Generally, the track and track bed performed as expected. The tendency for the concrete road bed to produce a fine powdery dust caused the shoes of the vehicle to pick up the dust, especially during high humidity conditions, and the results were shown in a considerable amount of apparent wear of the coloured, soft anodized surface of the rail. The wear was not measurable with the test equipment available i.e., less than 0.025 mm but, in some areas, the coloured layer was completely removed from the rail. This did not appear to effect the running of the vehicle during daily operation in dry weather, but the bare aluminum areas did tend to oxidize overnight, when the system was shutdown, and the drag rise following this was quite noticeable until considerable running repolished the rails. During the high drag conditions, stopping position control of the vehicle became irregular. The limited capacity of the computer memory of the programmable Logic Controller prevented total elimination of this problem. (See Section 2.3.6)

Heavy rain and a very wet track did not produce the above phenomena and, apart from obvious passenger discomfort from blowing mist caused by the air emission from the rails, the system operated satisfactorily. The washing action of heavy rain appeared to reduce the production of the powdery cement. Subsequent treatment of the concrete with a curing and sealing



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agent reduced the surface powdering and, combined with longer operational periods, the rails began to take on a noticeable "polished finish", and drag or friction was reduced dramatically.

During the early period of operation and, more specifically, during the commissioning phase, a number of heavy rainstorms coupled with high winds deposited a considerable amount of fine and coarse gravel on the rails. Running during these conditions caused very high drag and subsequent longitudinal scratching of the rail and shoe surfaces. This condition was reported in Test and Validation Report No. 447-610-014.
(Attached)

Brushes were mounted on the leading ends of each shoe carrier, and the shoes were replaced at 3370 trips of 33 metres for purposes of inspection and evaluation.

The brushes served to remove major debris from the rails, and the clean replacement shoes permitted an opportunity to closely study the wear patterns. This second set of shoes had accomplished over 30,000 trips when finally removed from service, illustrating the degree of improvement.

After the initial work of ensuring that the track was correctly secured and track gauge was maintained, no further problems developed, and the entire demonstration phase has been accomplished with only cursory attention to this detail.

Some recommendations are noted that should be applied to any commercial or public operation in order to ensure a trouble free operation.

- o Careful gauge (rail spacing) control.
- o Each rail laterally level.



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- o Careful joint control (butt and alignment).
- o Use of track cleaner brushes on shoe carriers.
- o Provision for expansion and contraction of the rails longitudinally in conjunction with the above.
- o Avoidance of abrasive contamination by attention to surroundings.

2.3.2 Shoes and Shoe Carriers

As noted in Section 2.3.1, the shoes suffered considerable longitudinal scratching following continuous operation while fine and coarse gravel was deposited on the track. These scratches tended to "pick up" the cement dust from the road bed, and the subsequent cement "paste" caused the brown anodized surface to wear away. The wear was not noticeable on the shoes but increased drag or friction was noted while the open aluminum surface of the rail was in the oxidized state. Subsequent "polishing" of the area reduced the drag significantly. When the "scratched" shoes were removed at 3370 trips for evaluation, a replacement set was installed, and 30,000 trips of operation had been accomplished before removal. The second set of shoes were still operational but were heavily scratched when a total power failure occurred during a violent rainstorm. The only other noticeable wear is at the leading and trailing ends of the shoes where the track touches the shoes during the swivel action in the turns. This also caused erratic vehicle drag.

The shoe carrier swivel action has since been permitted more freedom, and it is hoped that this will result in reduced wear in this area. A report on this condition is contained in Test and Validation Report 447-610-015. (Attached)



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2.3.3 Linear Induction Motors

During commissioning 8 of 21 motors were found to have unacceptable insulation. These motors were rewound or reinsulated as required and proved to be acceptable in service. The linear induction motors were originally installed having the windings dipped and sealed with epoxy for weather protection and a fibre plastic cover epoxied to the face of the laminations for surface protection. These operated satisfactorily, but the covers suffered damage from pedestrian traffic. Subsequently, a total encapsulation of a LIM in epoxy resin was carried out. This LIM was installed in the area of greatest pedestrian traffic and has proven successful over the full operating range of duty cycle and has sustained no damage. This LIM tends to run "hot to the touch", but is well within the operating temperature limits after continuous operation for thirty hours of regular duty cycle.

2.3.4 Reaction Rail

A reaction rail having greater thickness of the aluminum cap and reduced thickness of the back-iron was installed prior to the demonstration phase and has demonstrated improved performance, as well as being lighter in weight. This reaction rail was developed using data from the 60 Hz LIM program and resulted in reduced downforce. The aluminum cap was increased in thickness from $1\frac{1}{2}$ to 5 mm and the back iron reduced from 6 to 3 mm.

Some minor adjustment of the rail to LIM gap has been initiated to allow for shoe compression and to ensure less opportunity for striking the LIM while the vehicle is overloaded. There is reserve power available to accomplish this, and the system tends to run much smoother - (less jerk) with the greater gap, although load-weight compensation is not as good.

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2.3.5 Sensing Rail and Proximity Sensors

These items have been the cause of some concern during the demonstration phase. The limited range of the proximity sensors (13 mm), requires the sensing rail to proximity switch clearance to be maintained within extremely close tolerances or signals to the computer will be lost. It is recommended that proximity switches with much greater operating range be installed. The switches can then be installed "below grade", thereby ensuring protection from pedestrian traffic and other interferences and still permit an adequate signal to the computer. The sensors used proved time consuming to adjust to the ± 1 mm tolerance required.

2.3.6 Control System Operation

The Control System operated with the required reliability and ease of use with the exception of one feature, that is, the precise control of stopping position within the station. The major feature preventing complete solution of this problem was the limited memory size (1K) of the Texas Instrument's Programmable Logic Controller which had been selected to control all the system functions including:

- o Failure monitoring,
- o Vehicle position control,
- o Vehicle speed control,
- o Station operations.

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A simplified system block diagram is shown in Figure 2. The result of the limited memory size was that the stopping control was of an open-loop rather than closed-loop nature with a limited ability to compensate for changes in:

- o Track friction,
- o Vehicle mass,
- o Shoe condition,
- o Head or tail winds.

An attempt was made to correct the amount of braking applied by measuring the initial rate of deceleration and using a simple algorithm to vary the length of time over which reverse thrust was applied, and the time at which it was initiated. The total scatter in stopping position, if a simple fixed braking rate was used, would result in a scatter in stopping position of ± 0.2 m from a speed of 2 m/sec. The simple algorithm which resulted in "adaptable" open-loop gave a considerable improvement with a scatter in the range ± 0.1 m. Occasional under or overshoot of a further ± 0.1 m were experienced (perhaps 1 per 100 trips) which necessitated manual repositioning of the vehicle and system restart. It should be noted that the overshoot into the emergency zone was much rarer (perhaps 1 or 2 occurrences a week) and was never more than .6 m from the end of the desired stopping distance in normal operation.

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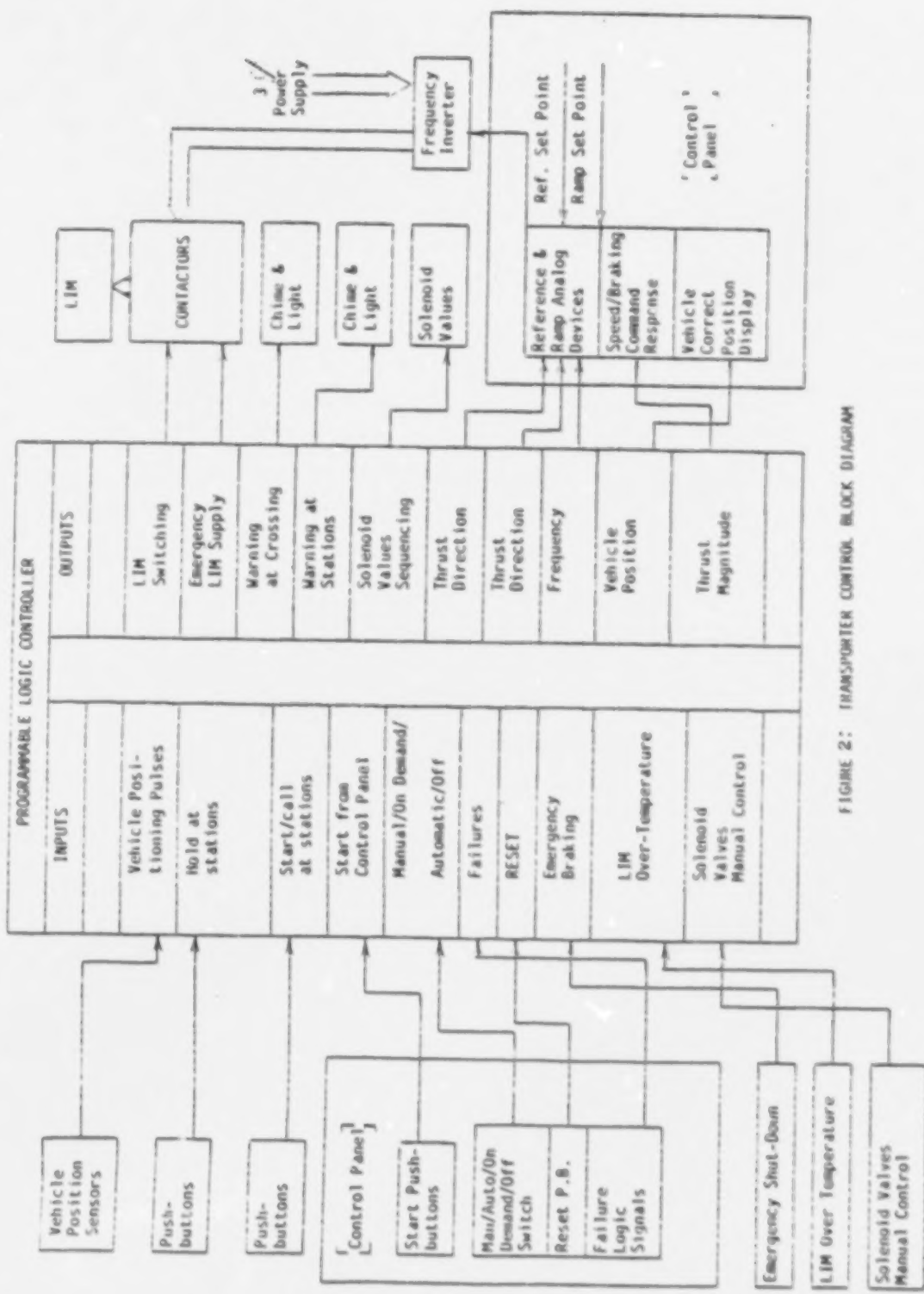


FIGURE 2: TRANSPORTER CONTROL BLOCK DIAGRAM



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In contrast, speed control in the cruise region proved to be better than anticipated with a range of some 16 steps in frequency between 15 and 50 Hz being sufficient to control vehicle speed under all conditions to 2 m/sec. with an error in the cruise region of less than 5%. Repeatability on total trip time was also much better than $\pm 5\%$.

2.3.7 Motor Drive Control - Frequency Inverter

A massive failure of the motor drive control was traced to a logic error allowing too many LIMs to be activated simultaneously. This severely impacted the operational demonstration running during the month of August. The inclusion of a "super fuse" to protect the frequency inverter rectified the problem, and further detail work subsequently prevented unplanned random activation of the sensitive "super fuse". The device consists of an extremely fast microprocessor controlled solid state circuit breaker in the DC link between rectifier and inverter in the motor drive unit. It senses overcurrent and shuts the system down in a safe manner. The motor drive control is now operating as planned.

2.3.8 Friction Tests

A series of friction tests at varying loaded weights and using no power to the LIMs were carried out. Thus, the drag is known and paves the way for further experiments on track drilling patterns, hole sizes, air pressure and air flow at the drilled holes. Friction levels reduced during operation of the track as both rails and shoes became polished to a value of .025 on straight track and .022 in the 70 m curves. These values are in fact below the expected levels determined in the conceptual design task (Milestone 1 Report 447-700-001). Also see 447-610-016 and 447-610-018 attached.

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The track joint misalignment and rough finish at the ends of the rail contributed to increased friction and shoe wear. Careful attention to the track joint alignment and gap is of great importance. Typically friction at the joints is double the normal values.

2.3.9 Demonstration of the System

During the continuous operating phase, every opportunity was taken to demonstrate the system. Varying loads of passengers, passengers plus added iron weight and empty vehicle operation, were demonstrated whenever possible. Although accurate records were not kept, approximately 20 groups of visitors representing government and industry, from several countries rode on the system.

2.4 PICTORIAL RECORD

During the course of the installation of the demonstration system a pictorial record was maintained, starting from the erection of the weather protection cover through to the demonstration phase.

A selected set of 35 mm slides and a videotape of the operating system is provided for the T.D.C. as part of this Report. (See Attachments).

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3.0

CONCLUSIONS AND RECOMMENDATIONS

The air bearing transportation system demonstration track has been installed, developed and demonstrated. During the course of the demonstration, 42,550 trips of 33 metres were completed successfully. The system continues to operate reliably, with the exception of the stopping algorithm. This problem is caused by the limited capacity of the computer programming features rather than any inherent difficulties with the Transporter system. It is recommended that the computer be updated to provide additional control memory, thus allowing more sophisticated programming and ensuring that operation through the total range of ambient temperature and humidity factors are conclusively acceptable.

The overall implications of the demonstration phase will be examined in more detail in the program Final Report.

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ATTACHMENT A - 35 MM SLIDES

Milestone Report #4

- 1) UTDC R&D - Presents - Transporter Installation
- 2) MCL Station (East End) Concrete Pour
- 3) R&D Station (West End) Cleared for Concrete Cure
- 4) Looking West - Concrete Cure - Note Heaters and Propane Tanks
- 5) Track Bed Cure - Piece of Rail in Slot to Show Curving Requirement
- 6) Cross Trency for Controls and Services
- 7) Heavy Snow Storm - Structure Torn Open by High Wind
- 8) Structure Removed - Track in Place - Wiring in Work
- 9) LIMs and Covers in Place - Chassis at MCL End
- 10) LIM Surrounds with Proximity Indicators
- 11) Car Chassis West from MCL Station on Test
- 12) Cross Walk
- 13) R&D End (West) Emergency Override Ramp and Stops
- 14) Operational Car in R&D Station - Note Ballast Weights
- 15) Moving Out of MCL Station
- 16) Car at Pedestrian Cross-Walk
- 17) Transporter in Continuous Operation
- 18) Reaction Rail and Sensing Rail
- 19) Shoe Wear After 1700 km - Note debris pick-up caused by operation on gravel covered track with poor air and drive control
- 20) Operational Compressor Site



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TRANSPORTER

Title

Test and Validation
Review 1st Set of
Vehicle Suspension Shoes

By

K.C.F.

Appd

TEST AND VALIDATION
REVIEW 1ST SET OF
VEHICLE SUSPENSION SHOES

Report No.: 447-610-014

Issue No.: 1

Copy No.:

Keith C. McConer

Originator

Keith C. McConer

Project Engineer

John G. Smith

Project Manager

Date: 84.09.28

Date: 84.10.30

UTDC Research & Development Ltd.

Project TRANSPORTER	Title Test and Validation Review 1st Set of Vehicle Suspension Shoes	Date 84.09.28	Issue 1	Page i of iii
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SUMMARY

The first set of suspension shoes fitted to the current transporter have been removed and examined for wear and general condition after 3371 - cycles of 33 meters. These shoes had previously been used on an experimental system for approximately 1,000 cycles of 45 meters.

A photographic record of the wear pattern is included.



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1.0

PURPOSE

To inspect and review conditions of the 1st set of Transporter vehicle suspension shoes after 3371 cycles of 33 meters.

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TRANSPORTER

Test and Validation
Review 1st Set of
Vehicle Suspension Shoes

2.0

PROCEDURE

The vehicle shoes were removed for examination of wear and/or damage to the shoe casing and the filler material.

Photographs were procured and form a part of this report. A set of slides were retained for illustration purposes.



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3.0 RESULTS

3.1 Generally, the shoes - (4 individual plastic oval tubes filled with close packed cellulose filler wrap) operated satisfactorily.

3.2 There is evidence of the filler material having absorbed considerable moisture even though they had been wrapped in a polyethylene cover and sealed with heavy duty duct tape. the tape came unstuck in several places during the course of the operational work and a number of holes or punctures were found in the covering - possibly due to the method of bolting the shoe to the carrier.

3.3 There is also evidence that, possibly due to the absorption of moisture, the filler material had packed down to a considerable degree without "recovering" the original shape.

3.4 The silicone impregnated polyethylene covers were considerably scratched longitudinally and contained "pick-up" in the form of a black soft composition believed to be a combination of shoe material, dirt and concrete dust. They also contained numerous small pieces of hard particles such as stone chips and metal chips.

3.5 During a previous inspection "in-situ", the debris embedded in the shoes was removed by a scraper and a dust cloth soaked in M.E.K.. This method of cleaning the shoes appeared to be of value but extreme or very deep scratches could not be removed satisfactorily.

3.6 The shoes were considered to be reusable if thoroughly cleaned, resurfaced and repacked with filler, but the rough surface may contribute to increased drag.



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3.7

A second set of shoes was installed after the 3371 cycles and have currently operated for 5473 cycles. These have sustained little wear or damage. This is attributed to meticulous cleaning of the rails on a daily basis combined with continuous operation, which tends to polish the rail to a very high sheen, thereby reducing drag dramatically. The new set of shoes will be the subject of a separate and later report.



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Review 1st Set of
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CONCLUSION

Generally the shoes are considered to have a long operational life if reasonably serviced at intervals. The report on the second set should verify this.



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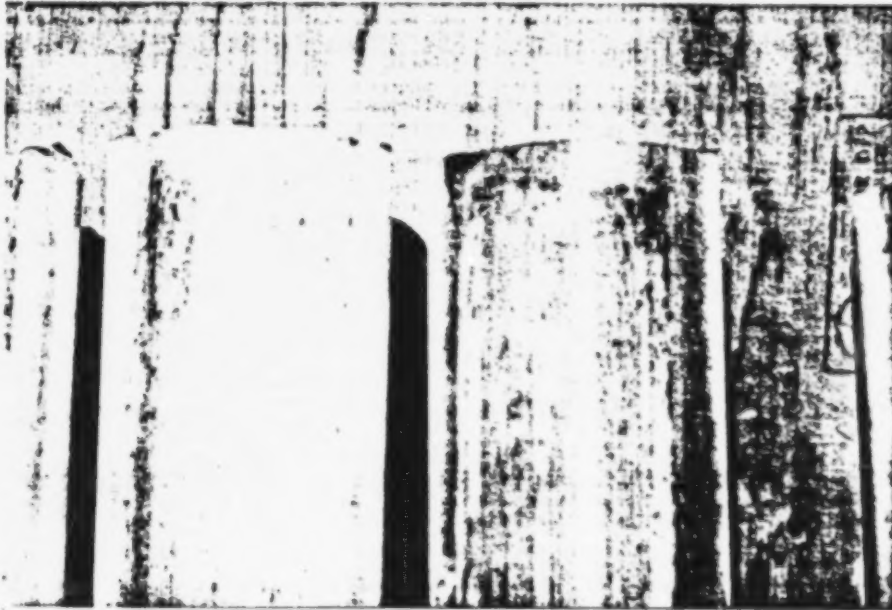
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Review 1st Set of
Vehicle Suspension Shoes

By

K.C.F.

Appd





UTDC Research & Development Ltd.

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447-610-015

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Title

TEST AND VALIDATION
REPORT 2ND SET OF
VEHICLE SUSPENSION SHOES

By

K.C.F.

Appd

TEST AND VALIDATION
REPORT ON 2ND SET OF
VEHICLE SUSPENSION SHOES

Report No.: 447-610-015

Issue No.: 1

Copy No.: 84.10.04

Keith C. Dwyer

Originator

Keith C. Dwyer

Project Engineer

S. J. Smith

Project Manager

Date: 84.10.09

Date: 84.10.11



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Title

TEST AND VALIDATION
REPORT 2ND SET OF
VEHICLE SUSPENSION SHOES

By

K.C.F.

Appd

SUMMARY

The second set of Transporter vehicle suspension shoes is inspected following a total shutdown of the system due to loss of ac power caused by weather related conditions. The shoes are considered serviceable for additional testing.



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TEST AND VALIDATION
REPORT 2ND SET OF
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2.0

CONDITIONS

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Title

TRANSPORTER

TEST AND VALIDATION
REPORT 2ND SET OF
VEHICLE SUSPENSION SHOES

By

K.C.F.

Appd

1.0

PURPOSE

To report on the state of the second set of vehicle suspension shoes following a complete loss of ac power and air pressure during a violent thunderstorm.



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Appd

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TEST AND VALIDATION
REPORT 2ND SET OF
VEHICLE SUSPENSION SHOES

2.0 CONDITIONS

- 2.1 The shoes had completed 8648 cycles of 33 metres on this test prior to the power failure and had been running through four hours of intermittent rain earlier in the day.
- 2.2 These shoes had previously been used on an experimental system for approximately 1000 cycles of 45 metres and had exhibited some light longitudinal scratching and polished areas but were in excellent condition.
- 2.3 Following the shut-down, the system was re-started and moved through two cycles under very high drag conditions when it was noted that the air system had also shut down resulting in a complete loss of suspension air cushion.
- 2.4 The heavy rain and high wind had deposited a considerable amount of gravel on the rails and the shoe brushes were unable to cope with the debris.
- 2.5 Since it was suspected that the shoes had sustained severe scratching, an inspection of the shoes was carried out.



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REPORT 2ND SET OF
VEHICLE SUSPENSION SHOES

3.0

RESULTS

3.1

The shoes had sustained a severe scratching but contained very few imbedded particles. The scattered black deposits were removed by light scraping and wiping with M.E.K. The shoes were considered serviceable for further running.

3.2

Due to a slight over-torquing of the shoe carrier spindle bolts, the articulation (horizontally) of the shoe undercarriage was severely restricted. This resulted in deep wear indentations where the leading end of the shoe contacted the upper section of the rail. This is illustrated in Fig. 1.

3.3

Following the cleaning of the shoes and the correction of the swivel mode, the vehicle was returned to service.

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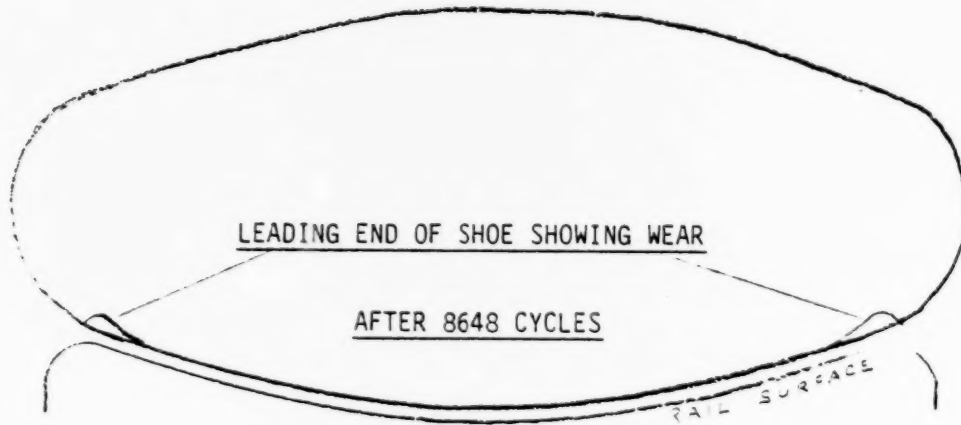


FIGURE 1



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Test and Validation
Operational Friction Test

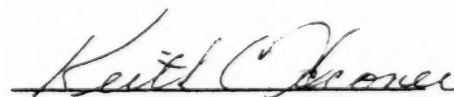
TEST AND VALIDATION
FRICTION TEST RECORD
AFTER 650 KM

Report No.: 447-610-016

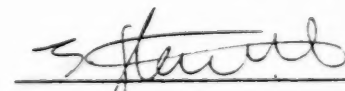
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Copy No.:

Originator



Project Engineer



Project Manager

Date: 84.10.15

Date: 84/11/19



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Transporter

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Test and Validation
Operational Friction Test

By

K.C.F.

Appd

SUMMARY

Friction or drag is recorded after the test vehicle has operated for more than 650 km, using the same set of suspension shoes.

Operation has been carried out under loaded and unloaded conditions and in all kinds of weather except freezing rain and snow, and the shoes are in very good condition.

The rail also displays a highly polished condition, and the rate of wear of the anodized surface has decreased as the system running snags have been reduced. The above distance represents nearly 20,000 trips from one station to the other, or over 800 trips per day average. Further friction tests will be recorded at the end of the demonstration phase and with modified hole patterns for air discharge in one section of track.



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Transporter

Title

Test and Validation
Operational Friction Tests

By

K.C.F.

Appd

1.0

PURPOSE

To report on the friction between the shoes and the rail after more than 650 km of operation (19,600 cycles).

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2.0 PROCEDURE

- 2.1 E.T.V. #2, with Disney body attached, was used for the test.
Weight of vehicle - 210 kg.
- 2.2 Air pressure was set at 19 P.S.I.G. at the drilled holes - all sections registered the same pressure and all holes were verified to be open, using a 0.025" pin drill.
- 2.3 A Hunter Force Gauge, Model D200M, S/N 317, was used to tow the vehicle with a three metre rope held at an angle of 5 - 10 degrees from horizontal.
- 2.4 Several runs were made in each direction and low and high readings for each section were recorded. The average reading was taken at a rate of two per metre.
- 2.5 Air control for each section was automatic and very reliable. The higher resistance noted while crossing each rail joint was significant.
- 2.6 The friction was noted on UTDC R&D Friction Test Record cards, and these form a part of this report (Ref. Tables 1, 2 and 3).
- 2.7 A sketch of the track bed is shown in Figure 1.
- 2.8 This report compares with the initial or preliminary report given at the beginning of testing (447-610-002 refers), and may be further compared with the report to be given at the end of the demonstration phase of the program.

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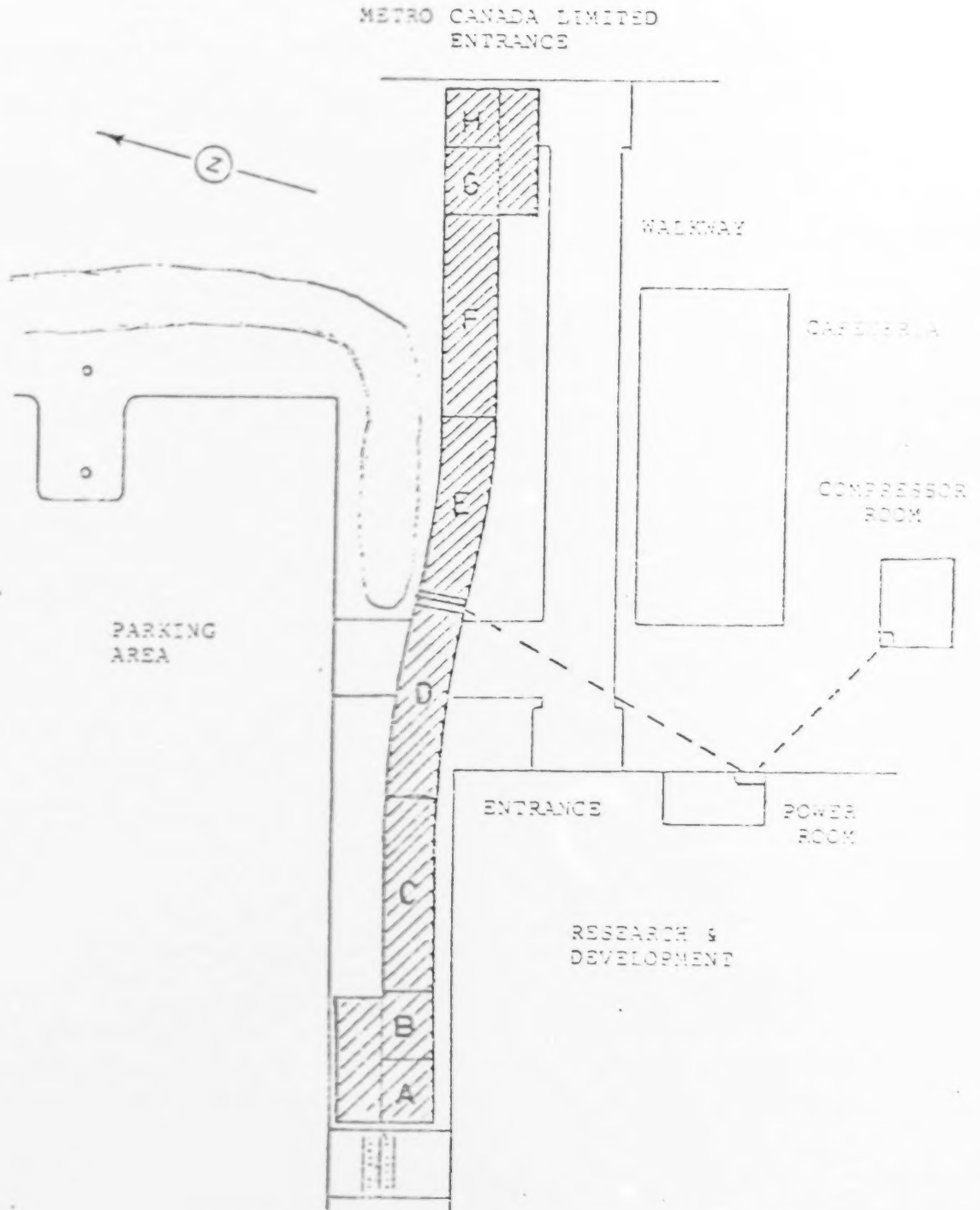


FIGURE 1: TRANSPORTER DEMONSTRATION TRACK LAYOUT



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Test and Validation
Operational Friction Tests

By

K.C.F.

Appd

3.0

CONCLUSION

The friction tests following over 650 km of operation indicate a dramatic reduction in drag now that the rails are well polished.

Friction at the rail joints is significantly higher than normal rail. This indicates that attention to detail assembly will result in a much improved friction condition.

The rails have had a large percentage of the original anodize finish removed due to heavy scratching during the earlier phase of the tests. Subsequent sealing of the cement surfaces of the track bed, stabilizing of the track-side ballast fill, and the addition of brushes in front of the shoes, has reduced the contamination to almost negligible proportions. The bare aluminum tends to oxidize over night, and this creates considerably higher drag until the surfaces become polished after a number of cycles or trips.



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Operational Friction Tests

By
K.C.F.

Appd

Vehicle: ETV #2 with Disney car Load: 210 kg A.U.W.
Run # : Cycle #18801 - Time 08:20 Amb Temp: +7°C -103.0 kP
Rail Air Press: 19 PSIG Wind: Light, Sky - Clear
(all sections)

Test Gauge: Hunter Force Gauge Model: D200m, S/N 317

Track Location: R&D/MCL

Track Polished and Dry

Shoes: 24" Articulated - Loose Pack

Section	Eastbound Force	Westbound Force		Hole Pattern
B	10-20	20-10		S W N
B-C Joint	30-20-30	30-20-30		/ /
C	10-40	10-18		/ /
C-D Joint	20-30-20	30-20-30		/ /
D	10-20	10-18		/ /
D-E Joint	30-20-35	30-20-30		/ /
E	10-10	10-20		/ /
E-F Joint	30-20-40	30-20-30		/ /
F	10-10	20-20		/ E /

At 6"
intervals
both rails

NOTES: Track joint friction - average - 30 lbs

- o Average track friction - 15.3 lbs
- o A number of high friction areas of short duration affect the low average friction
- o Shoes scratched on the bearing surface
- o The reduction in friction compared with Report 447-610-002 is dramatic

TABLE 1



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Operational Friction Tests

By

K.C.F.

Appd

Run # : Cycle #18803 - Time 08:20 (Four weights added)
Rail Air Press: 19 PSIG Amb Temp: +7°C -103.0 kP
(all sections) Wind: Light, Sky - Clear
Test Gauge: Hunter Force Gauge Model: D200m, S/N 317
Track Location: R&D/MCL
Track Polished and Dry
Shoes: 24" Articulated - Loose Pack

Section	Eastbound Force	Westbound Force	Hole Pattern
B	20-30	25-30	S W N / \
B-C Joint	35-40	30-40	/ \
C	10-18-20	20-18-20	/ \
C-D Joint	30-30	35-40	/ \
D	10-20-18	20-20-20	/ \
D-E Joint	25-30	30-40	/ \
E	10-10-10	20-20-20	/ \
E-F Joint	40-30	42-40	/ \
F	20-10-10	20-20-30	/ \
F-G Joint	20-20	40-50	/ E \
G	20-20-20	30-30-40	At 6" intervals both rails

NOTES: o Track joint friction - Average - 43.6 lbs
o Average track friction - 18.9 lbs

TABLE 2



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By

K.C.F.

Appd

Vehicle: ETV #2 with Disney car Load: 350 kg A.U.W.
Run # : Cycle #18805 - Time 08:50 (Four weights)
Rail Air Press: 19 PSIG Amb temp: +7°C -103.0 kP
(all sections) Wind: Light, Sky - Clear
Test Gauge: Hunter Force Gauge Model: D200m, S/N 317
Track Location: R&D/MCL
Track Polished and Dry
Shoes: 24" Articulated - Loose Pack

Section	Eastbound Force	Westbound Force	Hole Pattern
B	20-30	20-30	S W N
B-C Joint	40-30	40-30	
C	40-20	10-20	
C-D Joint	60-40	40-40	
D	20-20	20-20	
D-E Joint	50-40	40-40	
E	20-20	30-30	
E-F Joint	60-40	40-40	
F	20-10	20-30	
F-G Joint	40-30	50-40	E
G	20-20	20-30	At 6" intervals both rails

NOTES: o Track joint friction - 41.5 lbs
o Average track friction - 22.5 lbs

TABLE 3



UTDC Research & Development Ltd.

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TEST AND VALIDATION
FRICTION TEST RECORD AFTER
1400 KM

Report No.: 447-610-018

Date: 05 November 1984

Keith C. Dwyer
Project Engineer

S. Hunt
Project Manager

Date: 14:11:05

Date: 84/11/19



UTDC Research & Development Ltd.

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Test and Validation
Operational Friction Test

By

K.C.F.

Appd

SUMMARY

Friction or drag is recorded after the test vehicle has operated for more than 1,400 km. The friction tests were taken after the third set of shoes had been installed and operated for 317 km. The second set of shoes had been operated for 1,152 km when excessive wear on the leading ends of the shoes required their removal. Friction tests were not recorded for the second set of shoes immediately prior to the removal from the vehicles, but the physical operation indicated a very low drag on a dry, polished track. This was typically on the order of 10 to 20 pounds force. Friction is also recorded with a modified hole pattern in one section of track.



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Test and Validation
Operational Friction Test

By

K.C.F.

Appd

1.0

PURPOSE

1.1

To report on the friction between the vehicle shoes and the rail after 1,400 km of operation under varying load conditions and in all kinds of weather, except freezing rain and snow.

1.2

To report on the friction when additional holes are drilled in one section of rail. The holes are drilled along the centre line of the rail in the vertical mode at six inch intervals (152 mm) using a #72 drill (.025"). The tangential holes are .025". The original tangentially drilled holes (at six inch intervals) remain for the first part of the test, and the last part of the tests is accomplished with the tangential holes plugged with epoxy.

1.3

To report on the friction when no air is available from the drilled holes, i.e., the air compressor system is turned off.



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By

K.C.F.

Appd

- 2.0 PROCEDURE
- 2.1 All testing for friction was carried out using the Engineering Test Vehicle chassis #2 with the Disney Body attached. Total weight of the vehicle is 210 kg.
- 2.2 Varying loads were available in the form of 36 kg sections of iron rail. A total load of eight rail weights represents a full load, and the all-up weight of the loaded vehicle is 500 kg.
- 2.3 Air pressure was set at 20 P.S.I.G. at the drilled holes. All sections registered the same pressure and all holes were verified to be open, using a .025" pin drill.
- 2.4 Several runs were made in each direction, and low and high readings for each section were recorded. The average reading was taken at a rate of two per metre.
- 2.5 The friction was noted on UTDC R&D Friction Test Record cards, and these form a part of this report (Ref. Tables 1 through 11).
- 2.6 A sketch of the track bed is shown in Figure 1.
- 2.7 This report compares with the initial or preliminary report (447-610-002) and the further report (447-610-016) which was issued after 650 km of operation.

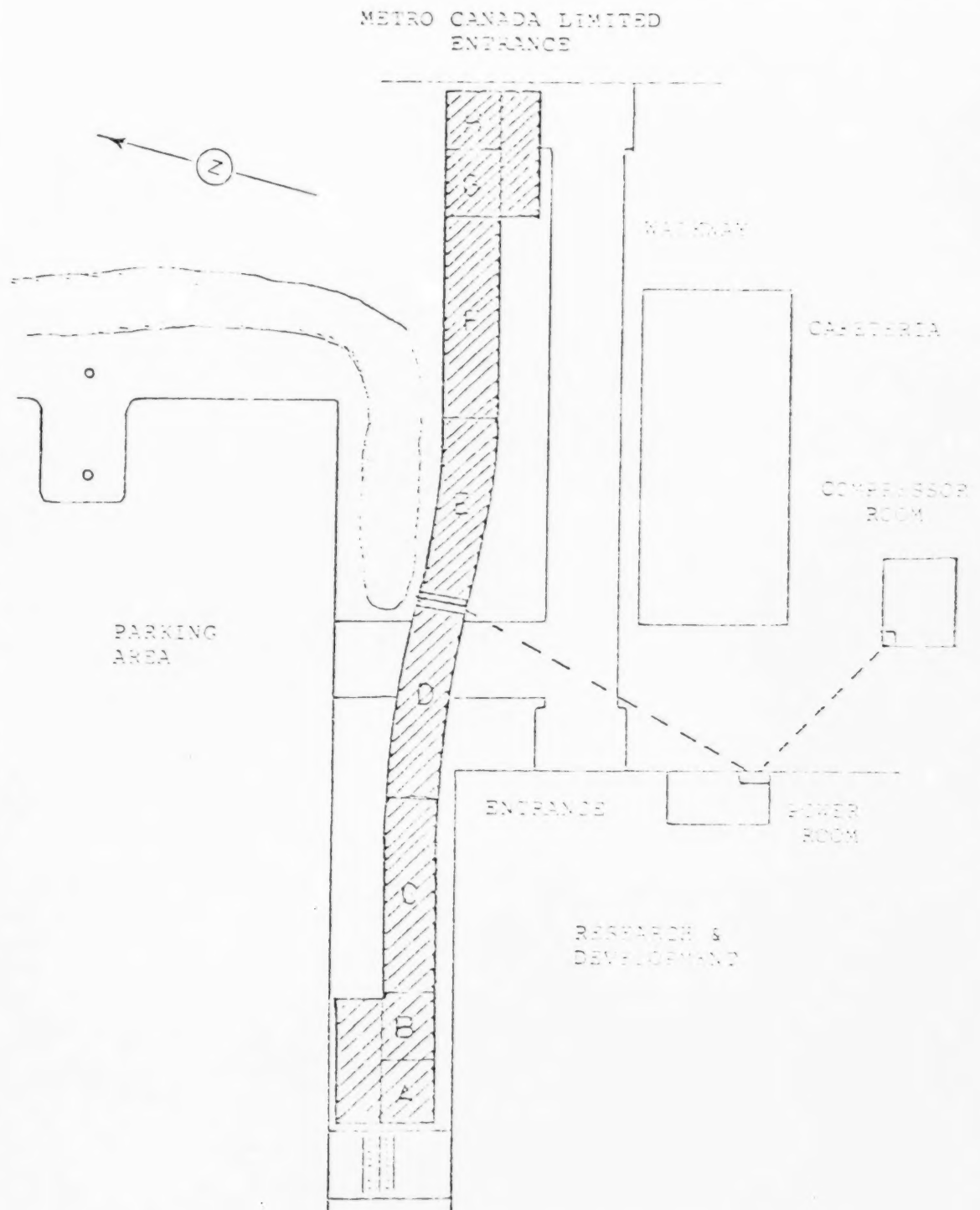


FIGURE 1: TRANSPORTER DEMONSTRATION TRACK LAYOUT



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K.C.F.

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3.0

RESULTS

The friction tests, however carefully carried out, indicated considerable scatter over a relatively small range of readings. Some of this may have been caused by variations in rail surface and track spacing gauge.

A number of tests appear to have been affected by a very strong wind blowing along the directional layout of the trackway. Some air current interference by adjacent buildings no doubt modified the wind factor. A very clean, dry trackway and a well polished rail, with well bedded shoes, required very little effort to start an empty vehicle moving down wind. Variations in track surface and track joints were the chief cause of any retardation in this case. Additional effort was required to move the vehicle into wind, thus indicating that the wind factor must be considered.

The average coefficient of friction, empty through fully loaded, on the straight line track was .025. The track joints in this area increased to .044.

The average coefficient of friction, empty through fully loaded, on the curved section of track was .022. The track joints in this area indicated .041. The expected higher friction on the curved section of track was observed in only a few scattered areas. The areas of higher friction along the whole length of track were easily identified with the "worn" or "clear" areas where the colour anodize was removed. These areas were chiefly at the track butt joints, which were known to be less than satisfactory, and at a number of areas in the straight section which were suspected of being slightly "twisted" or not "true" to gauge.



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K.C.F.

Appd

The average coefficient of friction, empty vehicle, on a polished and dry track without the air bearing cushion was .257.

The variations in hole drilling in Section C of the rails did not appear to significantly affect the observed results, although there is some evidence that the extra air available during the "double drilled" period reduced the starting friction to some degree.

The vertically drilled holes in Section "C" did produce a rather spectacular "fountain effect" in wet weather, compared with the tangentially drilled holes.



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Test and Validation
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K.C.F.

Appd

4.0

CONCLUSION

The friction tests at the conclusion of the demonstration phase have been recorded. A comparison with additional air discharge holes vs the six inch spaced tangentially drilled holes and with the vertical hole drilling is shown in the appended friction test record cards.

During the course of the final friction tests it became evident that changes in ambient temperature and humidity, as well as wind speed, have a significant effect on the friction. Further testing on an open track may be required if the wind factor is to be fully identified.



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Test and Validation
Operational Friction Test

By

K.C.F.

Appd

Vehicle: E.T.V. #2 with
Disney Car

Load: 350 kg A.U.W.
(4 weights)

Run Cycle: 19,608 - Time 16:00

Amb Temp: +8°C

Rail Air Press: 20 PSIG

Wind: Light

(all sections)

Sky: Clear

Test Gauge: Hunter Force Gauge

Model: D200M, S/N 317

Track Location: MCL/R&D

Track: Polished and dry

Shoes: 24" articulated - loose pack

Preliminary check on New Hole Pattern at "C". Two tests were run.

Section	Eastbound Force	Westbound Force		Hole Pattern	
C	Average 6	Average 11.75		0.025" x 0.025"	0.025" x 0.025"
C	15	13.3	Overall Average 14	0.025" x 0.025"	0.025" x 0.025"
All holes drilled .025"				S E N 6" spacing between each type of hole both rails	

APPENDIX I



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Test and Validation
Operational Friction Test

By

K.C.F.

Appd

Vehicle: E.T.V. #2 with
Disney Car

Load: 210 kg A.U.W.
(no payload)

Run Cycle: 20,757 - Time 13:00

Amb Temp: +10°C

Baro.: 120.2 kP

Rail Air Press 20 PSIG

Wind: Light, Sky: Clear

Test Gauge: Hunter Force Gauge

Model: D200M, S/N 317

Track Location: MCL/R&D

Track: Polished and dry

Shoes: 24" articulated - loose pack

Check on new hole pattern - Section "C".

Section	Eastbound Force	Westbound Force		Hole Pattern
B	18	B 10		W
B - C	20	C - B 22	Joint	
C	10	C 7		
C - D	19	D - C 15	Joint	
D	10	D 10		
D - E	30	E - D 22	Joint	
E	9	E 9		
E - F	30	F - E 22	Joint	
F	9	F 8		
F - G	20	G - F 20	Joint	
G	10	G 10		
				S N
				E

APPENDIX II



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K.C.F.

Appd

Vehicle: E.T.V. #2 with
Disney Car

Load: 210 kg A.U.W.
(no payload)

Run Cycle: 20,759 - Time 13:10

Amb Temp: +10°C

Rail Air Press: 20 PSIG

Wind: Light, Sky: Clear

Test Gauge: Hunter Force Gauge

Model: D200M, S/N 317

Track Location: MCL/R&D

Track: Polished and dry

Shoes: 24" articulated - loose pack

Second check on new hole pattern at "C".

Section	Eastbound Force	Westbound Force		Hole Pattern
B	10	10		
B - C	22	C - B 20	Joint	
C	12	8		
C - D	18	D - C 20	Joint	
D	10	10		
D - E	26	E - D	Joint	
E	9	9		
E - F	10	F - E 23	Joint	
F	10	10		
F - G	20	G - F 20	Joint	
G	10	18		
APPENDIX III				S E N



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Test and Validation
Operational Friction Test

By

K.C.F.

Appd

Vehicle: E.T.V. #2 with
Disney Car

Run Cycle: 23,135 - Time 10:30

Rail Air Press: 20 PSIG

Test Gauge: Hunter Force Gauge

Track Location: MCL/R&D

Track: Polished and drying

Shoes: 24" articulated - loose pack

Check with payload - hole pattern "C".

Load: 350 kg A.U.W.
(4 weights)

Amb Temp: +10°C

Baro.: 102.0 kP

Humidity: 88%

Wind: Light

Sky: Clear/cloudy

Model: D200M, S/N 317

Section	Eastbound Force	Westbound Force		Hole Pattern
B B - C	30 40	25 C - B 45		W
C C - D	15 40	12 D - C 20		S/O/C
D D - E	19 20	19 E - D 30		
E E - F	19 40	19 F - E 35		
F F - G	15 40	20 G - F 30		
G	30	32		
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Test and Validation
Operational Friction Test

By

K.C.F.

Appd

Vehicle: E.T.V. #2 with
Disney Car

Run Cycle: 23,137 - Time 10:45

Rail Air Press: 20 PSIG

Test Gauge: Hunter Force Gauge

Track Location: MCL/R&D

Track: Polished and dry

Shoes: 24" articulated - loose pack

Second check with payload - hole pattern "C"

Load: 350 kg A.U.W.
(4 weights)

Amb Temp: +12°C

Baro.: 102.0 kP

Humidity: 88%

Wind: Light

Sky: Cloudy/clear

Model: D200M, S/N 317

Section	Eastbound Force	Westbound Force		Hole Pattern
B B - C	35 45	25 C - B 45		W
C C - D	16 30	12 D - C 35		
D D - E	18 20	14 E - D 20		
E E - F	19 40	19 F - E 35		
F F - G	19 30	20 G - F 30		
G	25	30		
APPENDIX V				S E N



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Project

Title

Transporter

Test and Validation
Operational Friction Test

By

K.C.F.

Appd

Vehicle: E.T.V. #2 with
Disney Car

Run Cycle: 23,139 - Time 11:00

Rail Air Press: NONE

Test Gauge: Hunter Force Gauge

Track Location: MCL/R&D

Track: Polished and dry

Shoes: 24" articulated - loose pack

Check resistance - NO AIR TO TRACKLoad: 210 kg A.U.W.
(no payload)

Amb Temp: +12°C

Baro.: 102.0 kP

Wind: Light

Sky: Clear/cloudy

Model: D200M, S/N 317

Section	Eastbound Force	Westbound Force		Hole Pattern
B	105 - 110	NOT		W
C	120 - 125			
D	130 - 125	TAKEN		
E	120 - 125			
F	125 - 130			
G	105 - 110			
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Title

Transporter

Test and Validation
Operational Friction Test

By

K.C.F.

Appd

Vehicle: E.T.V. #2 with
Disney Car

Run Cycle: 42,992 - Time 11:00

Rail Air Press: 20 PSIG

Test Gauge: Hunter Force Gauge

Track Location: MCL/R&D

Track: Polished and dry

Shoes: 24" articulated - std. pack (2nd set)

Check resistance - with new shoes and new hole pattern at
section "C".

Load: 350 kg A.U.W.
(4 weights)

Amb Temp: +14°C

Baro.: 102.1 kP

Humidity: 71%

Wind: W.S.W. 50 km,

Sky: Clear

Model: D200M, S/N 317

Section	Eastbound Force	Westbound Force	Hole Pattern
B B - C	40 46	C - B 40	W A
C D - D	31 40	D - C 42	o o o
D D - E	28 40	E - D 38	o o o
E E - F	30 45	F - E 45	o o o
F F - G	28 35	G - F 30	o o o
G	35	22	o o o
			S E N

NOTE: Higher resistance may be caused by new shoes not
"bedded" in properly.

APPENDIX VII



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By

Appd

K.C.F.

Project

Title

Transporter

Test and Validation
Operational Friction Test

Vehicle: E.T.V. #2 with
Disney Car

Load: 210 kg A.U.W.
(no payload)

Run Cycle: 42,994 - Time 11:15

Amb Temp: +14°C

Rail Air Press: 20 PSIG

Wind: WSW 50 km

Sky: Clear

Test Gauge: Hunter Force Gauge

Model: D200M, S/N 317

Track Location: MCL/R&D

Track: Polished and dry

Shoes: 24" articulated - Std. pack (2nd set)

Check resistance - New shoes and new hole pattern at section
"C". Recheck run 42,992.

Section	Eastbound Force	Westbound Force	Westbound Force	Hole Pattern
B B - C	30 35	C - B 30 35	30	W / / / /
C C - D	20 40	D - C 20 35	22	/ / / / / /
D D - E	20	E - D 20 25		/ / / / / /
E E - F		F - E 20 35		/ / / / / /
F F - G		G - F 22 30		/ / / / / /
G				/ / / / / /
APPENDIX VIII				S E N



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Project Transporter	Title Test and Validation Operational Friction Test
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Vehicle: E.T.V. #2 with Load: 500 kg A.U.W.
Disney Car (8 weights)
Run Cycle: 43,490 - Time 14:30 Amb Temp: +15°C
Baro.: 101.8 kP
Humidity: 60%
Rail Air Press: 20 PSIG Wind: W.N.W. 35 km,
Sky - Cloudy
Snow flurries in AM
Amb Temp +4°C
Test Gauge: Hunter Force Gauge Model: D200M, S/N 317
Track Location: MCL/R&D
Track - Polished and dry - warm air supplied
Shoes - 24" articulated - std. pack (2nd set)
Check resistance - full load - eight weights

Section	Eastbound Force	Westbound Force	Hole Pattern	
B	35	45	/ / /	W
B - C	40	45		
C	35	35	o o o	o o o
D - D	40	50		
D	35	35	/ / /	/ / /
D - E	40	40		
E	30	30	/ / /	/ / /
E - F	45	45		
F	35	35	/ / /	/ / /
F - G	40	80		
G	40	80	/ / /	/ / /
			S	N
			E	

NOTE: Readings at "B" and "G" are not reliable due to short "pull angle" of tow rope.



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Project

Transporter

Title

Test and Validation
Operational Friction Test

By

K.C.F.

Appd

Vehicle: E.T.V. #2 with

Disney Car

Load: 350 kg A.U.W.

(4 weights)

Run Cycle: 43,492 - Time 11:45

Amb Temp: +15°C

Baro.: 101.8 kP

Rail Air Press: 20 PSIG

Wind: WNW 35 km

Sky: Cloudy

Test Gauge: Hunter Force Gauge

Model: D200M, S/N 317

Track Location: MCL/R&D

Track: Polished and dry - warm air supplied

Shoes: 24" articulated - Std. pack (2nd set)

Check friction - half load - 4 weights

Section	Eastbound Force	Westbound Force		Hole Pattern
B B - C	20 25	20 30		
C C - D	20 35	20 30		
D D - E	20 20	20 25		
E E - F	20 35	20 30		
F F - G	25 45	20 30		
G	25	30		
APPENDIX X				



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Project

Title

Transporter

Test and Validation
Operational Friction Test

By

K.C.F.

Appd

Vehicle: E.T.V. #2 with
Disney Car

Load: 210 kg A.U.W.
(no payload)

Amb Temp: +15°C

Run Cycle: 43,494 - Time 14:50

Baro.: 101.8 kPa

Rail Air Press: 20 PSIG

Wind: WNW 35 km

Sky: Cloudy/fair

Test Gauge: Hunter Force Gauge

Model: D200M, S/N 317

Track Location: MCL/R&D

Track: Polished and dry - warm air supplied

Shoes: 24" articulated - Std. pack (2nd set)

Check friction - no load

Section	Eastbound Force	Westbound Force	Hole Pattern	
B B - C	10 25	10 30	S W	N E
C C - D	10 22	10 22		
D D - E	10 20	10 20	S W	N E
E E - F	10 22	10 22		
F F - G	10 15	10 15	S W	N E
G	10	10		
APPENDIX XI				